



Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-77

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AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-77**

19 May 1996

Contributions By:

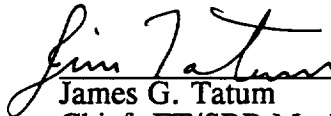
NASA, Lockheed-Martin, Rockwell, and Thiokol Members of the
Debris/Ice/TPS and Photographic Analysis Teams

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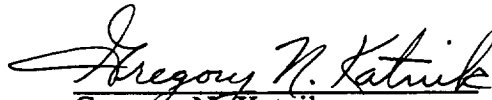


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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.



Photo 1: Launch of Shuttle Mission STS-77

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 18 May 1996. The detailed walkdown of Pad 39B and MLP-1 also included the primary flight elements OV-105 Endeavour (11th flight), ET-78 (LWT 71), and BI-080 SRBs. There were no significant vehicle or pad anomalies.

The vehicle was cryoloaded for flight on 19 May 1996. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. One IPR was taken for a depression near the southwest GOX vent seal caused by the seal bungee cord. No acreage icing or frost conditions were expected due to the time of year. There were no ice/frost conditions or protuberance icing conditions outside of the established data base.

After the 6:30 a.m. (local) launch on 19 May 1996, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal.

A total of 109 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission. SSME ignition appeared normal.

No stud hang-ups occurred on any of the holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes.

ET/Orbiter umbilical films revealed part of the +Y bipod jack pad closeout (4-inches long by 4-inches wide) was missing. The resulting divot went to substrate and exposed primer. Similarly, a 4-inch long by 3-inch wide divot to substrate was centered between the bipods in the LH2 tank-to-intertank flange closeout. Approximately 30 small, shallow divots occurred in intertank stringer valleys in an area around the -Y bipod spindle housing closeout/ramp. Approximately 10 similar divots were located around the +Y bipod ramp and 4 shallow divots were visible in the LH2 tank acreage just aft of the -Y bipod. Missing foam from the forward inboard corner of the pressurization line ice/frost ramp at XT-1464 revealed substrate primer. The divot was approximately 4-inches long by 2-inches wide. A divot in the -Y thrust strut flange closeout was estimated to be 12 inches long by 4 inches wide by 1 inch deep. Erosion of the +Y flange closeout was visible. The large lightning contact strip across the forward part of the LO2 ET/ORB umbilical was missing. Loss of lightning contact strips has been the subject of previous IFAs.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. The number of MSA-2 debonds on both frustums was less than average.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

A post landing inspection of OV-105 was conducted 29 May 1996 on SLF runway 33 at the Kennedy Space Center. The Orbiter TPS sustained a total of 81 hits, of which 17 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of hits and the number of hits 1-inch or larger was less than average.

The Orbiter lower surface sustained a total of 48 hits, of which 15 had a major dimension of 1-inch or larger. The largest lower surface tile damage site involved three tiles on the right chine and measured 3.5-inches long by 2.25-inches wide by 0.375-inch maximum depth. Hits on the right side along a line from nose to tail are generally attributed to ice impacts from the ET LO2 feedline bellows and support brackets.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. Three clips were missing from the EO-3 salad bowl fitting. All debris retention devices had closed properly and no ordnance fragments were found on the runway beneath the umbilical cavities. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples from the facility environment, SRB BSM exhaust, Orbiter RCS nozzle cover adhesive, Orbiter TPS, and paints/primers from various sources. These residual sampling data do not indicate a single source of damaging debris as all of the noted materials have previously been documented in post-landing sample reports. The residual sample data showed no debris trends when compared to previous mission data.

A total of eight Post Launch Anomalies, but no In-Flight Anomalies (IFAs), were observed during the STS-77 mission assessment.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 17 May 1996 at 1400 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

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S. Otto	LMSO - LSS ET Processing

3.0 LAUNCH

STS-77 was launched at 96:140:10:30:00.009 GMT (6:30 a.m. local) on 19 May 1996.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 18 May 1996. The detailed walkdown of Pad 39B and MLP-1 also included the primary flight elements OV-105 Endeavour (11th flight), ET-78 (LWT 71), and BI-080 SRBs. There were no significant vehicle or launch pad anomalies.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 19 May 1996 from 0125 to 0310 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. One TPS IPR was taken. No acreage icing or frost conditions were expected due to the ambient conditions at this time of year. There were no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients.

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The R2R, L4L, and L3D RCS thruster covers were tinted green indicating a small internal vapor leak. Less ice/frost than usual had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces. Only condensate was present on the SSME #3 heat shield. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers averaged 71-76 degrees F. Temperatures measured by the SRB Ground Environment Instrumentation (GEI) ranged from 73-78 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 75 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a general comparison to infrared scanner point measurements. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank. TPS surface temperatures ranged from 60-68 degrees F. PR ET-78-TS-0025 (IPR 77V-0120) was taken on a 0.5-inch diameter by 0.125-inch maximum depth depression near the southwest GOX vent seal caused by the seal bungee cord. MRB acceptance to use as-is was obtained with no constraint for flight.

The intertank acreage exhibited no TPS anomalies. Ice/frost accumulation on the GUCP was typical.

There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost accumulation, was present on the acreage. TPS surface temperatures ranged from 61-68 degrees F. A crack, 10-inches long by 1/4-inch wide, was present in the -Y vertical strut attachment fitting fairing forward surface TPS. The presence of the crack was acceptable for flight per NSTS-08303 criteria. There were no anomalies on the new-method bipod jack pad closeouts.

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

There were no ice/frost team observations entered in OMI S6444 and no anomalies detected during OTV surveillance and final inspection.

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch.

No leaks were observed on the GUCP or either of the LO2 and LH2 Orbiter T-0 umbilicals.

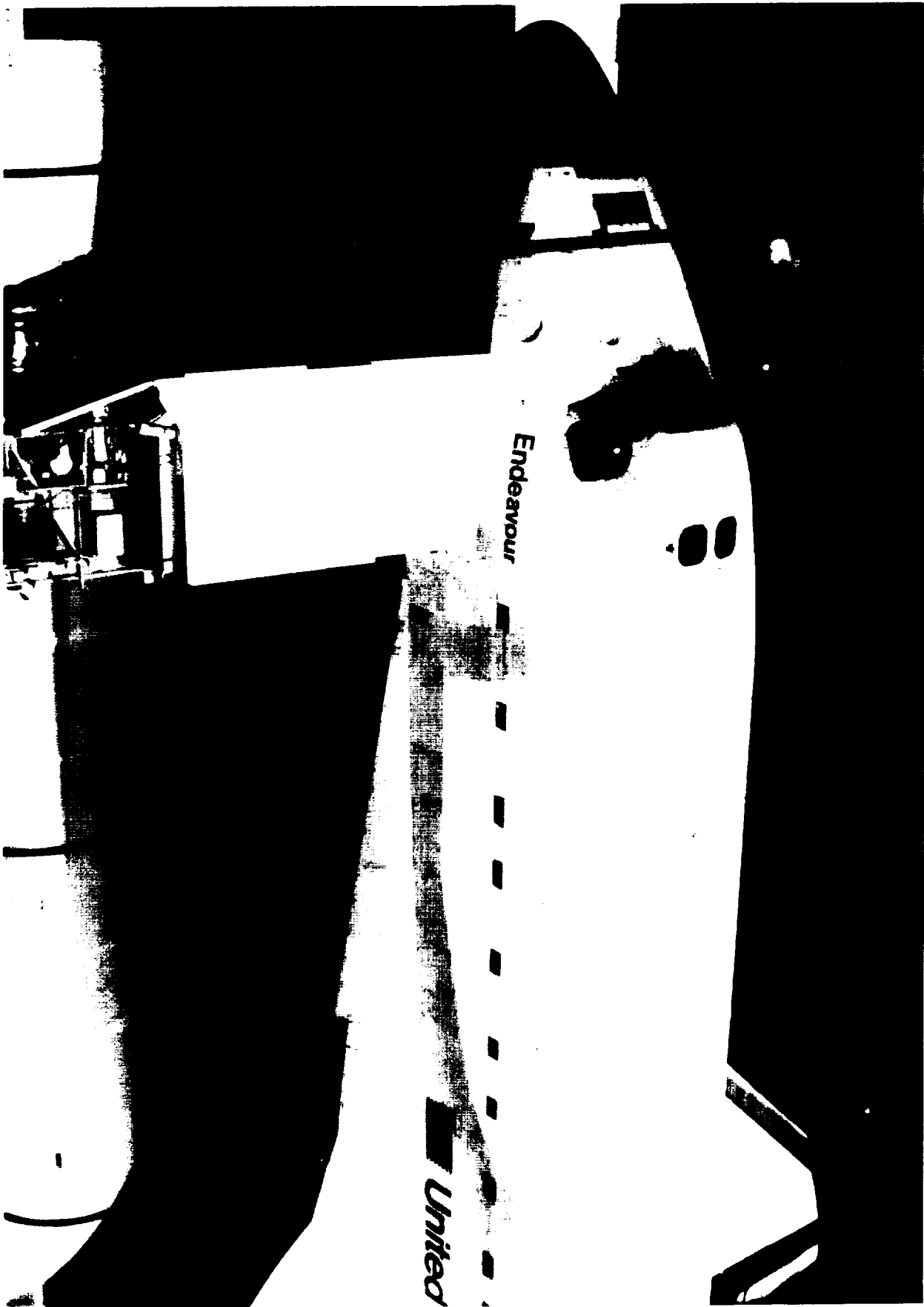


Photo 2: STS-77 Cryoloaded for Launch
OV-105 Endeavour (11th flight), ET-78 (LWT 71), and BI-080 SRBs

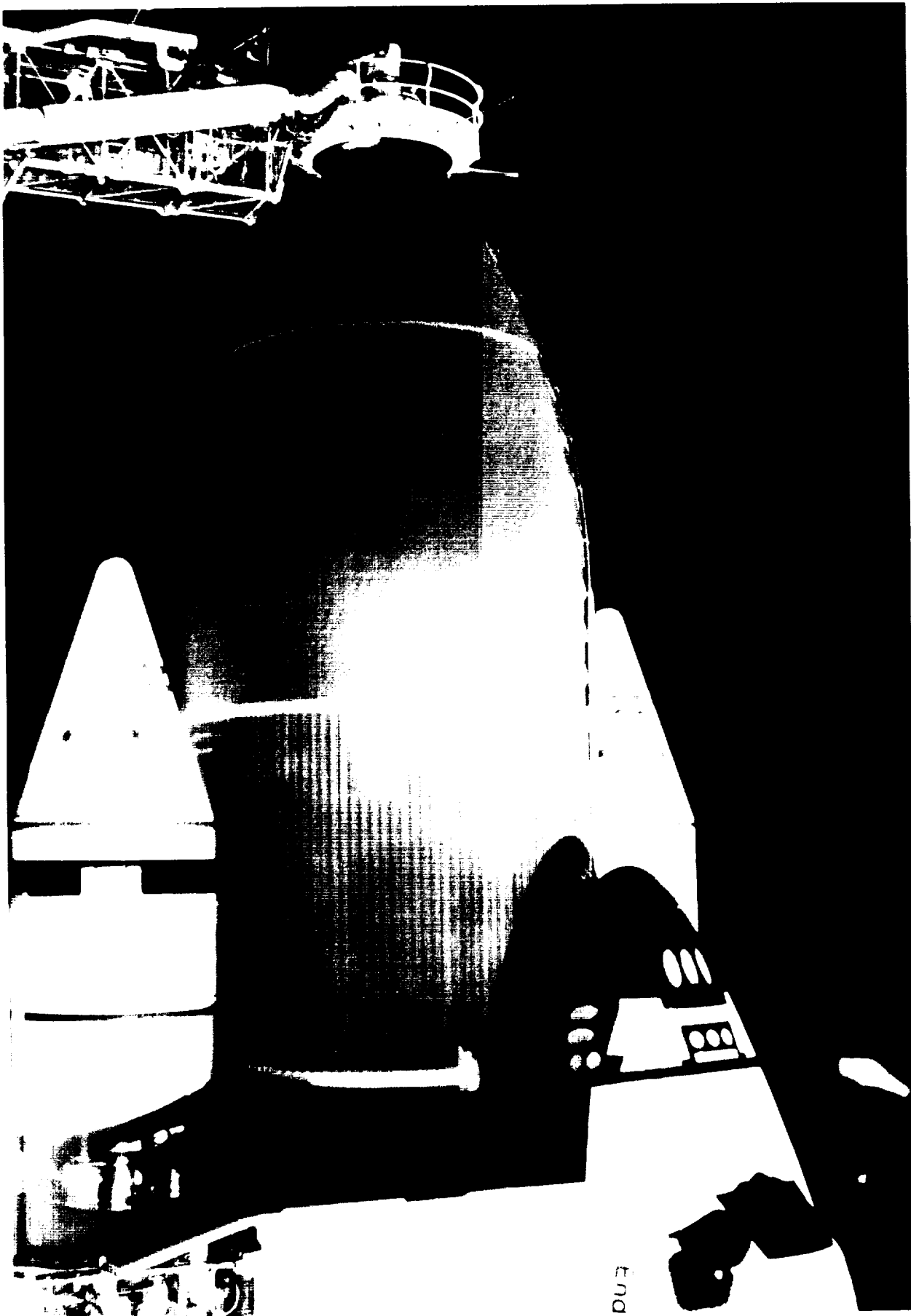


Photo 3: ET-78 Cryoloaded for Launch



Photo 4: Overall View of SSMEs

Less ice/frost than usual had formed on the SSME #1 and #2 heat shield-to-nozzle interfaces. Only condensate was present on the SSME #3 heat shield. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

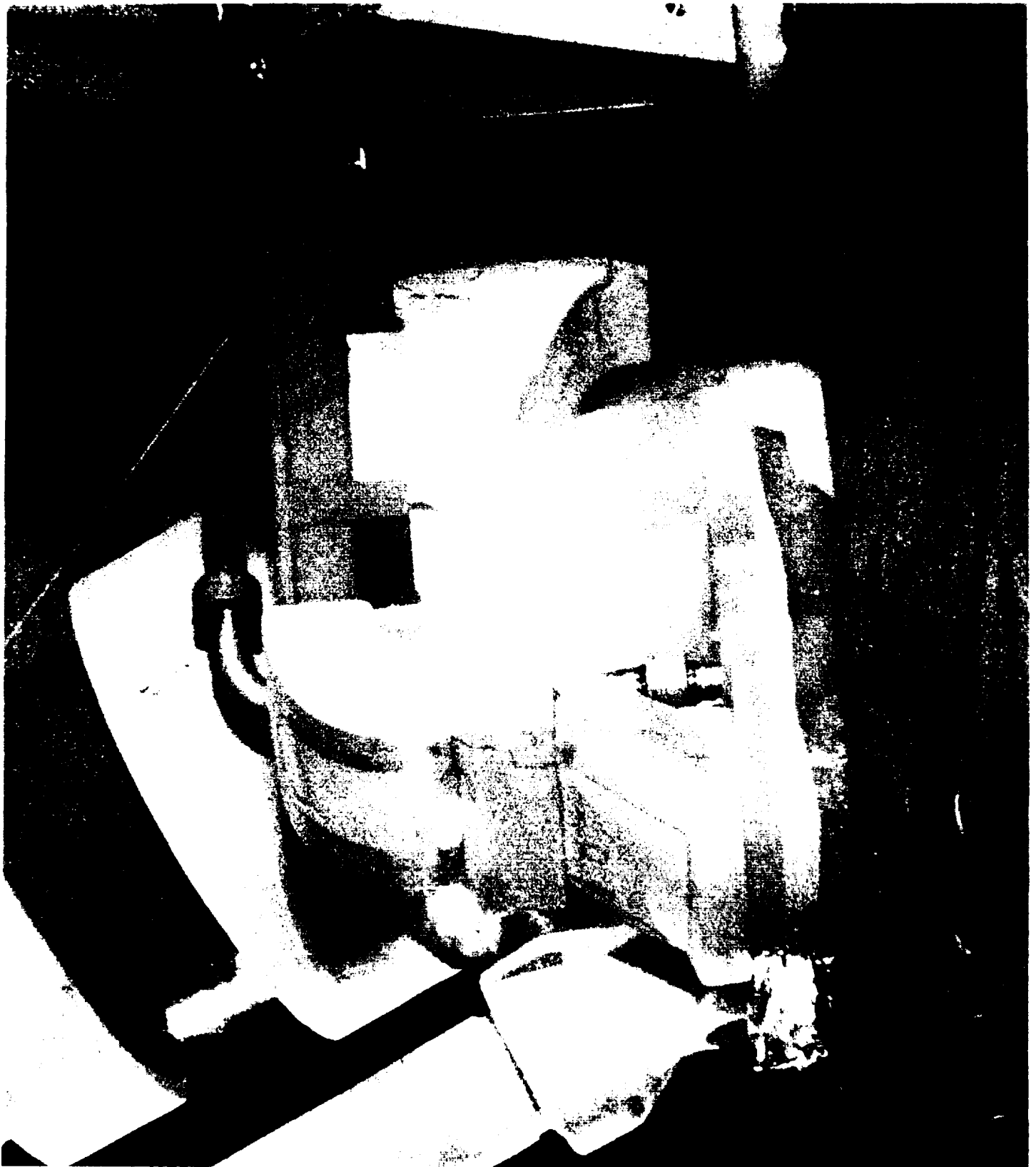


Photo 5: ET/Orbiter LH2 Umbilical

Less than usual amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS, RSS, and Pad B crawlerway/acreage was conducted on 19 May 1996 for two hours starting at Launch + 2 hours.

No flight hardware or TPS materials were found.

South SRB HDP erosion was typical. All south HDP shoe shim material was intact. No HDP stud hang-up is expected based on the observations of the post launch assessment team and the vehicle liftoff lateral acceleration of 0.08gs reported by Rockwell-Downey. A piece of bolt 1-1/4 inch by 7/8 inch diameter was found on top of the HDP #2 stud. All of the north HDP doghouse blast covers were in the closed position. Erosion of the blast covers was typical.

The Tail Service Masts (TSM), Orbiter Access Arm (OAA) and GOX Vent Arm (GVA) appeared undamaged. No topcoat from the External Tank nose cone adhered to the GOX seals; however a small black spot (approximately 1/4 inch dia.) was observed on the southwest seal, possibly from the epoxy ink used for the seal alignment grid that was touched-up at the pad.

The GH2 vent line had no loose cables (static retract lanyard), and appeared to have latched properly with no rebound. The GUCP legs and crossbeam showed no obvious signs of contact by the static retract lanyard. The vent line was latched on the eighth tooth of the latching mechanism. The RSS cable had disconnected properly.

Typical pad damage included:

- 2 removable handrails on MLP 0-level east side were loose-to-the-touch

- A loose OIS cable was found at FSS 115-foot level

- Separated light fixture on the north side of the FSS 175 foot level

- A placard for the 75-foot level scrubber was found at pad apron

Overall, damage to the pad appeared minimal.

Post launch pad inspection anomalies are listed in Section 9.

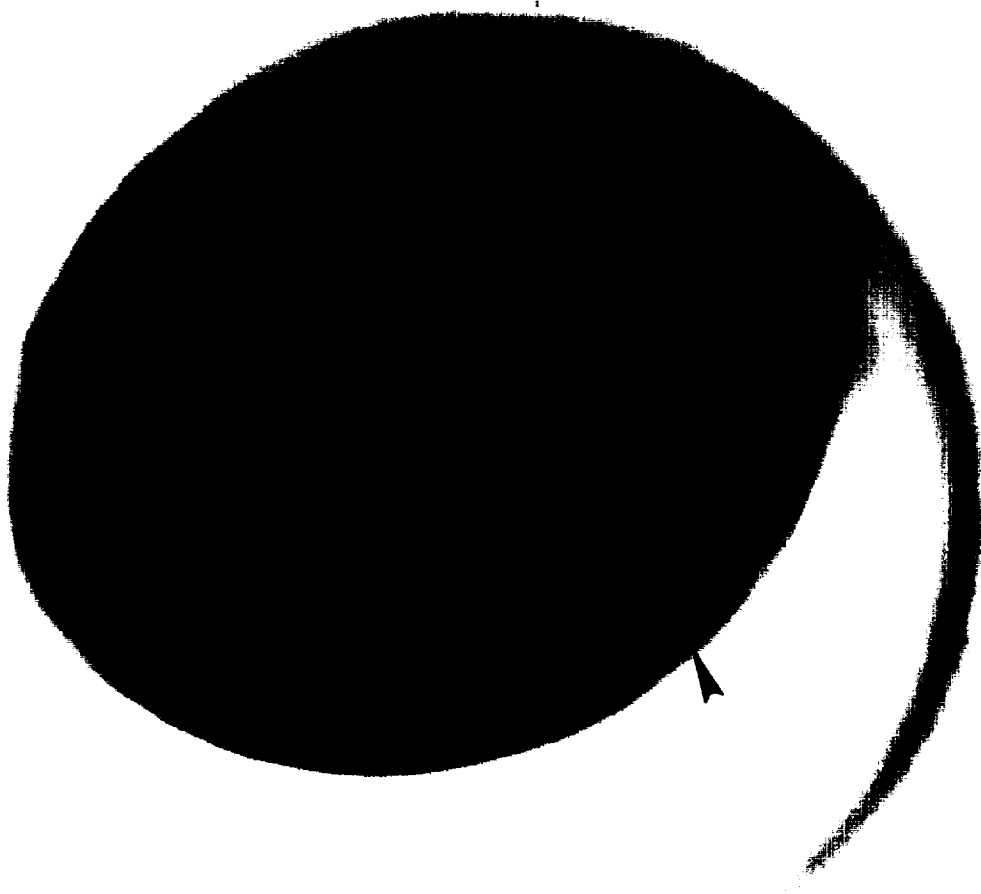


Photo 6: Debris on HDP #2 Stud

A piece of bolt 1-1/4 inch by 7/8 inch diameter was found on top of the HDP #2 stud.

5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFAs were generated as a result of the film review. Post flight anomalies are listed in Section 9.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 85 films and videos, which included twenty-eight 16mm films, eighteen 35mm films, and thirty-nine videos, were reviewed starting on launch day.

Frost, but no ice, coated the GOX vent louvers. There was no discernible damage to TPS on the ET nose cone, fairing, or footprint area (OTV 160, 161, 162).

SSME #3 may have been a slow starter causing the Mach diamond to form after the SSME #2 Mach diamond. Free burning hydrogen drifted north under the body flap and upward to the OMS pods during start-up (OTV 151, 163, 170, 171; E-19, -20, -76).

The effects of aspiration were clearly visible on the MLP deck with small pieces of facility debris during SSME start-up (OTV 163).

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals. Several pieces of ice contacted the LH2 umbilical cavity sill and were deflected outward. No tile damage was visible. A piece of light-colored debris approximately 5-inches long by 0.5-inches wide originated from an area behind the LH2 feedline. The object may have been ice or RTV. At the same time, a small dark particle estimated to be 0.5-inches in length originated from the LH2 cable tray elbow area (OTV 109, 164).

A long, thin, white object entered the upper field-of-view near the left inboard elevon during SSME ignition at 10:29:57.200 and fell past the body flap. The object may be a GSE tile shim (E-16).

A thin, flexible, rectangular object, possibly paper or a tag, entered the field-of-view from above near the elevon and fell past SSME #2 at 10:29:58.913 GMT. The origin of the object has not been determined.

Three rectangular pieces of facility debris moved across the field of view close to the camera prior to liftoff (E-34).

No stud hang-ups occurred on any of the holddown posts. One dark particle was visible falling downward between the aft skirt and the holddown post #5 shoe. However, the particle has not been identified as an ordnance or frangible nut fragment (E-12). Similarly, another dark particle fell from the area of the HDP #6 stud hole to the shoe (E-13).

Numerous pieces of SRB throat plug material and shredded SRB sound suppression water trough material were ejected out of the SRB exhaust holes and passed by the SRB aft skirts moving away from the vehicle shortly after T-0 (E-1, -15, -16, -52, -222, -224).

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 149, 150, 170, 171).

GUCP disconnect from the ET was nominal. However, a piece of foam, approximately 2-inches long by 1.5-inches wide, was torn loose by GUCP retraction from the adjacent -Z stringer (E-33; OTV 104).



Photo 7: SSME Start-Up

SSME #3 may have been a slow starter;visually the Mach Diamond on SSME #2 formed before SSME #3.



Photo 8: Debris Near Body Flap

A long, thin, white object entered the upper field-of-view near the left inboard elevon during SSME ignition at 10:29:57.200 and fell past the body flap. The object may be a GSE tile shim.



Photo 9: GUCP Disconnect

GUCP disconnect from the ET was nominal. However, a piece of foam, approximately 2-inches long by 1.5-inches wide, was torn loose by GUCP retraction from the adjacent -Z stringer.

A piece of cord, believed to be from the sound suppression water troughs, moved from right to left across the field-of-view at 10:30:00.825 GMT.

Four light-colored objects fell vertically through the field of view past the vehicle at T+7, 9, 12, and 16 seconds MET. The objects are believed to be birds (unfocused) and not near the SSV (E-54, -222).

A flash occurred in the SSME #2/#3 plume at T+40 seconds MET (OTV 13, 21). Two more flares occurred in the SSME plume during ascent (E-205, -208, -222, -223, -224).

Localized flow condensation collars formed on the vehicle for 6 seconds starting at T+41 seconds MET (OTV 4B, 21). Local flow condensation collars were expected for the ambient weather conditions (E-207, -213, -222, -223, -224).

Numerous small light-colored objects, most likely pieces of SRB aft skirt instafoam, fell along side the SRB plumes during ascent (E-52, -57, -59, -220).

Body flap movement (amplitude and frequency) appeared similar to previous flights (E-207, -212, -213).

Condensation/water vapor was visible streaming aft from the -Z side of the External Tank during ascent (E-224).

ET aft dome charring, exhaust plume recirculation, and SRB separation appeared normal. Numerous pieces of slag were visible falling from the SRB nozzles and exhaust plume after separation (OTV 13; E-207, -208, -212).

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-105 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Data was obtained from all three cameras. Hand held photography by the flight crew consisted of six images.

SRB separation from the External Tank was nominal.

ET-78 separation from the Orbiter was also nominal.

The umbilical films showed possible loss of foam from a portion of the pressurization line ice/frost ramp at XT-760. Some minor erosion of LO2 tank acreage TPS had occurred in an area on the ogive +Y side of the pressurization line/cable tray.

Part of the +Y bipod jack pad closeout (4-inches long by 4-inches wide) was missing. The resulting divot went to substrate and exposed primer. Similarly, a 4-inch long by 3-inch wide divot to substrate was centered between the bipods in the LH2 tank-to-intertank flange closeout. Loss of this TPS in flight most likely contributed to the number of Orbiter lower surface tile damage sites greater than 1-inch in size.

Approximately 30 small, shallow divots occurred in intertank stringer valleys in an area around the -Y bipod spindle housing closeout/ramp. Approximately 10 similar divots were located around the +Y bipod ramp and 4 shallow divots were visible in the LH2 tank acreage just aft of the -Y bipod.

Missing foam from the forward inboard corner of the pressurization line ice/frost ramp at XT-1464 revealed substrate primer. The divot was approximately 4-inches long by 2-inches wide.

A divot in the -Y thrust strut flange closeout was estimated to be 12 inches long by 4 inches wide by 1 inch deep. Erosion of the +Y flange closeout was visible.

The LH2 ET/ORB umbilical appeared to be in good condition with no TPS damage. Foam was eroded from the horizontal (clamshell) section of the cable tray and the aft surface of the -Y vertical strut.

The LO2 ET/ORB umbilical also appeared to be in good condition with no TPS damage. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. The large lightning contact strip across the forward part of the umbilical was missing. Loss of lightning contact strips has been the subject of previous IFAs.

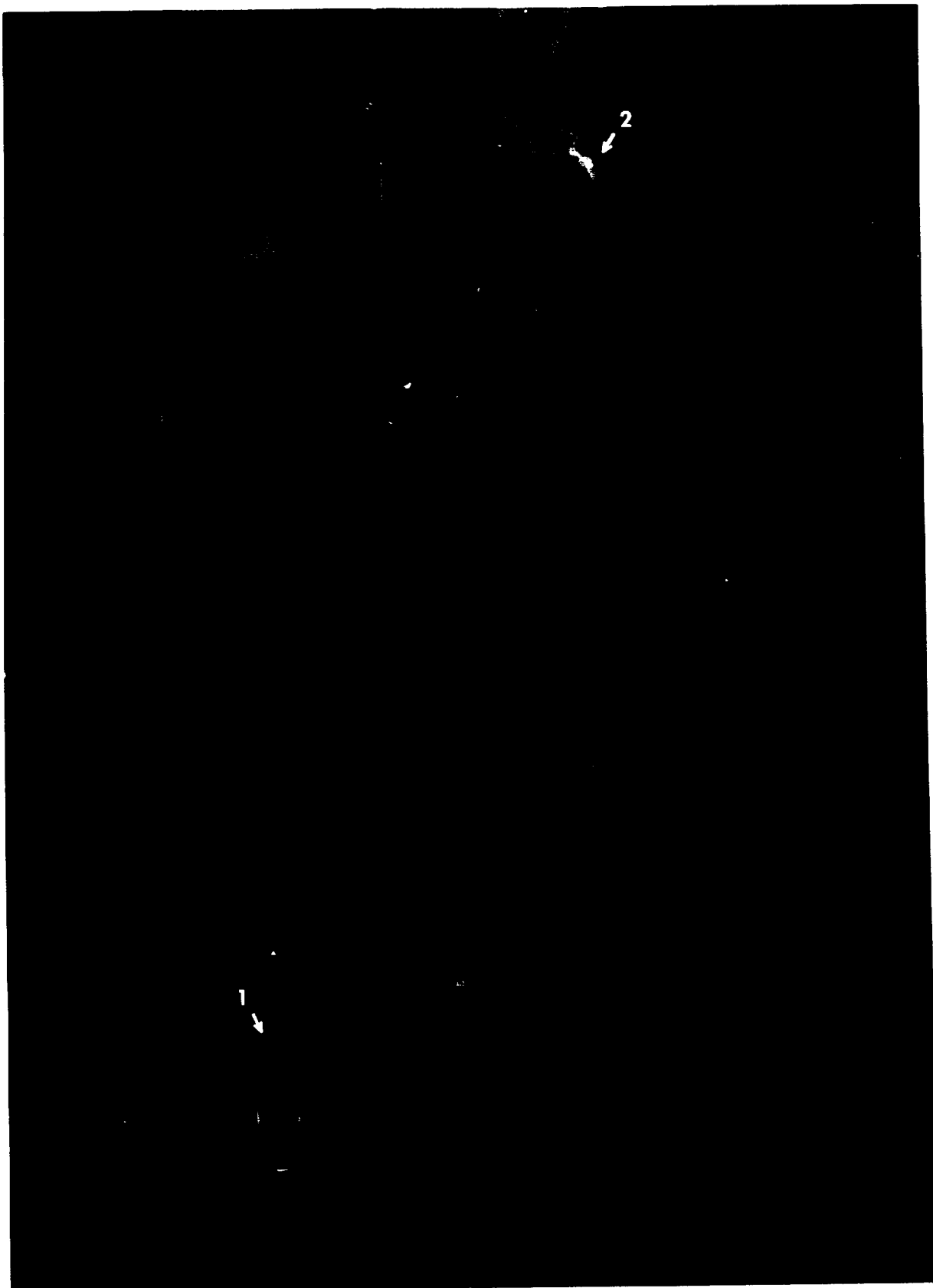


Photo 10: ET Separation from Orbiter

The LO2 ET/ORB umbilical appeared to be in good condition with no TPS damage. The large lightning contact strip across the forward part of the umbilical was missing (1). Loss of lightning contact strips has been the subject of previous IFAs. Erosion of the +Y flange closeout was visible (2).

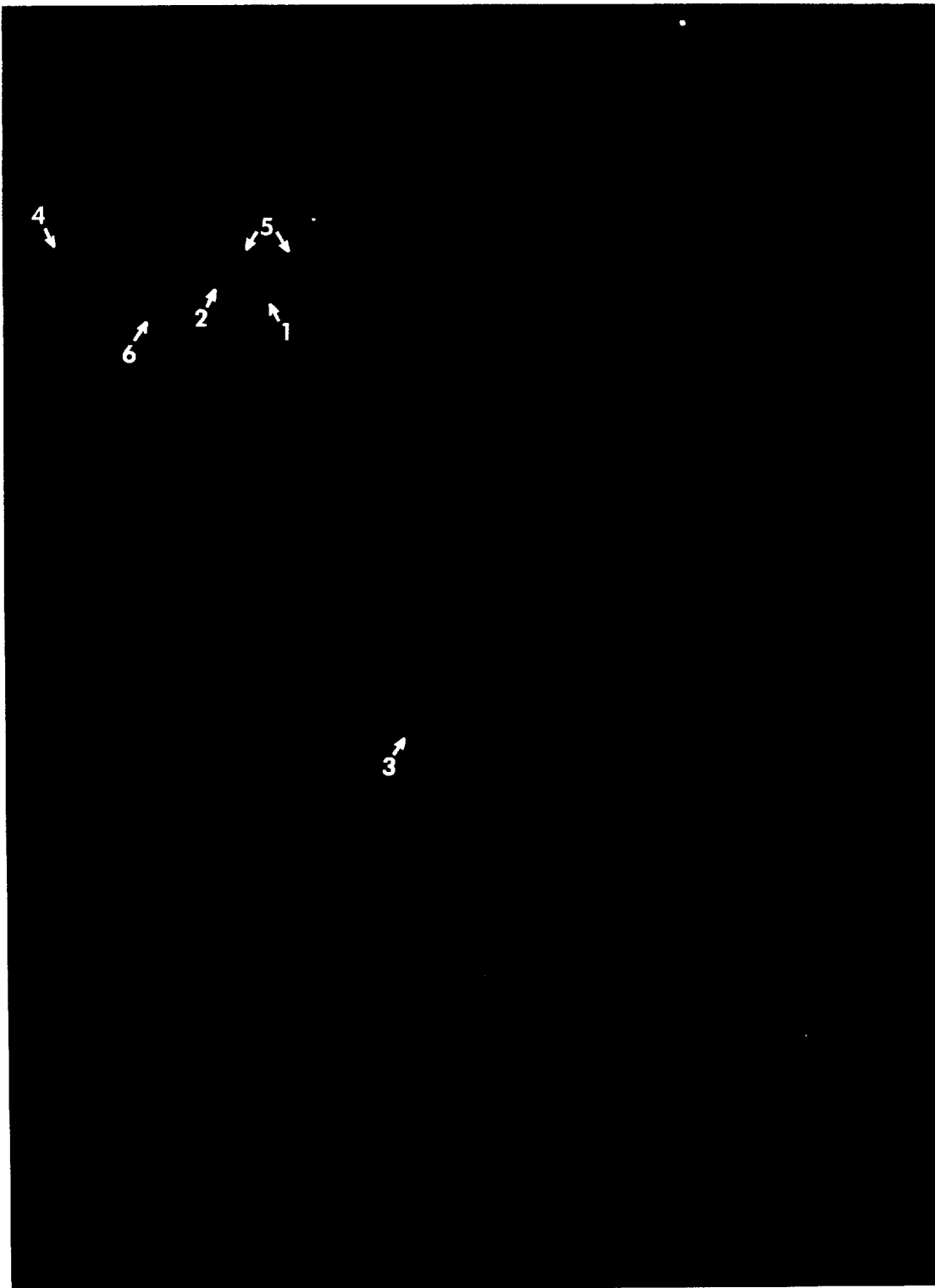


Photo 11: Upper ET Separation from Orbiter

Part of the +Y bipod jack pad closeout (4-inches long by 4-inches wide) was missing; the resulting divot went to substrate and exposed primer (1). A 4-inch long by 3-inch wide divot centered between the bipods in the LH2 tank-to-intertank flange closeout went to substrate (2). Foam (4-inches long by 2-inches wide) missing from the forward inboard corner of the pressurization line ice/frost ramp at XT-1464 revealed substrate primer (3). Approximately 30 small, shallow divots occurred in intertank stringer valleys in an area around the -Y bipod spindle housing closeout/ramp (4), 10 similar divots were located around the +Y bipod ramp (5), and 4 shallow divots were visible in the LH2 tank acreage just aft of the -Y bipod (6).

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 21 films and videos, which included eight 35mm large format films, two 16mm high speed films, and eleven videos, were reviewed.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. Left and right main landing gear touchdown was virtually simultaneous at approximately 1700 feet. The Orbiter rolled west of centerline while the drag chute was deployed, then was steered back to centerline.

Drag chute deployment appeared nominal.

Touchdown of the nose landing gear was smooth.

No significant TPS damage was visible. The reddish-brown discoloration from a previous flight on the forward section of the left payload bay door appeared unchanged. Rollout and wheel stop were uneventful.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-080 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 21 May 1996. From a debris standpoint, both SRBs were in excellent condition.

6.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The RH frustum was missing no TPS. The number of debonds over fasteners (24) was average (Figure 4). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position.

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

Aft skirt MSA-2 was intact. More than usual amounts of foam were missing from the aft skirt aft ring. This condition was probably the result of the foam adhesion problem documented prior to launch. Launch films showed numerous light colored particles, believed to be pieces of foam, falling along side the SRB plumes during ascent.

The HDP Debris Containment Systems (DCS) appeared to have functioned properly and all the plungers were seated.

STS-77 RIGHT SRB FRUSTUM

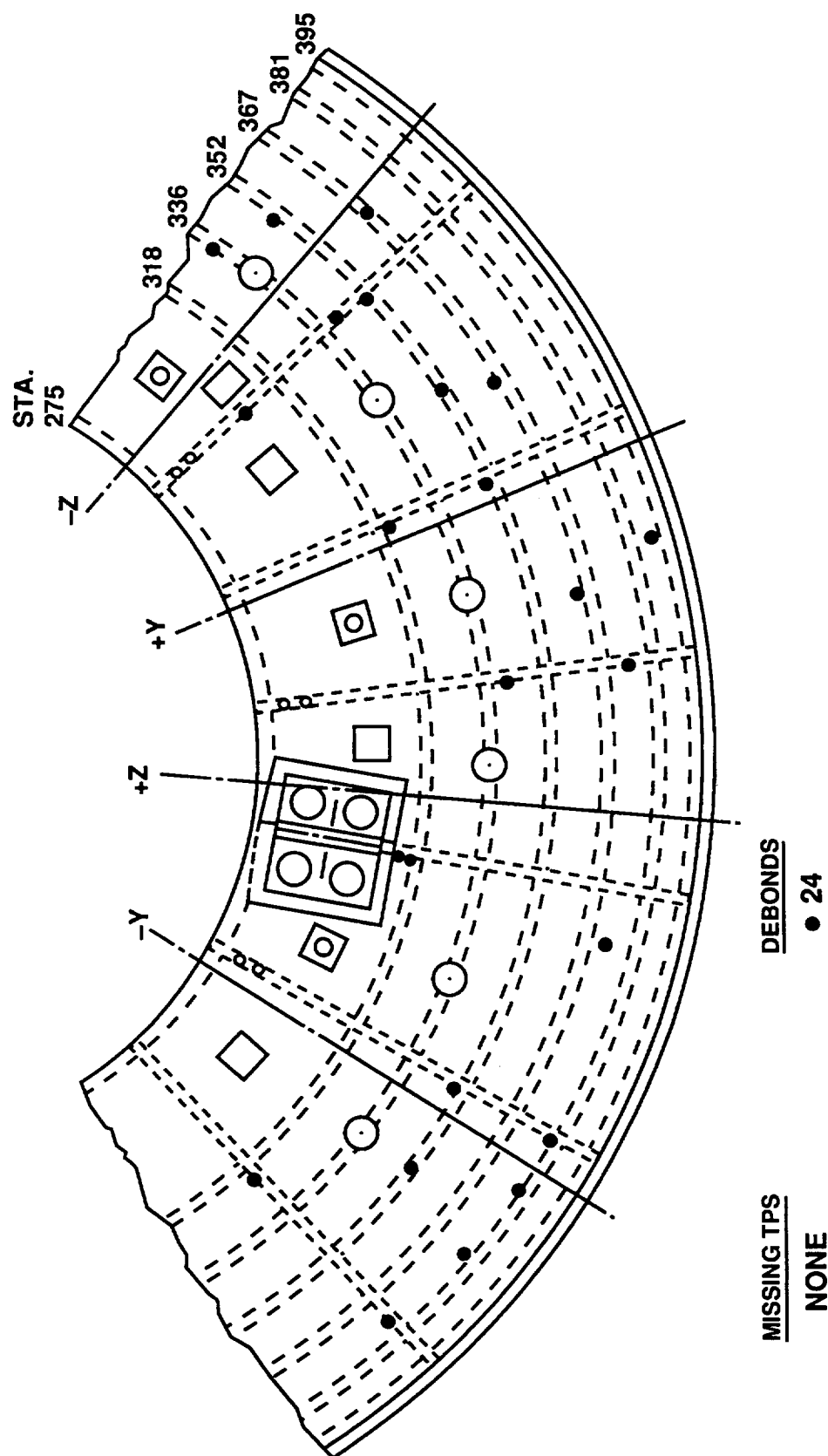


Figure 1: RH SRB Frustum

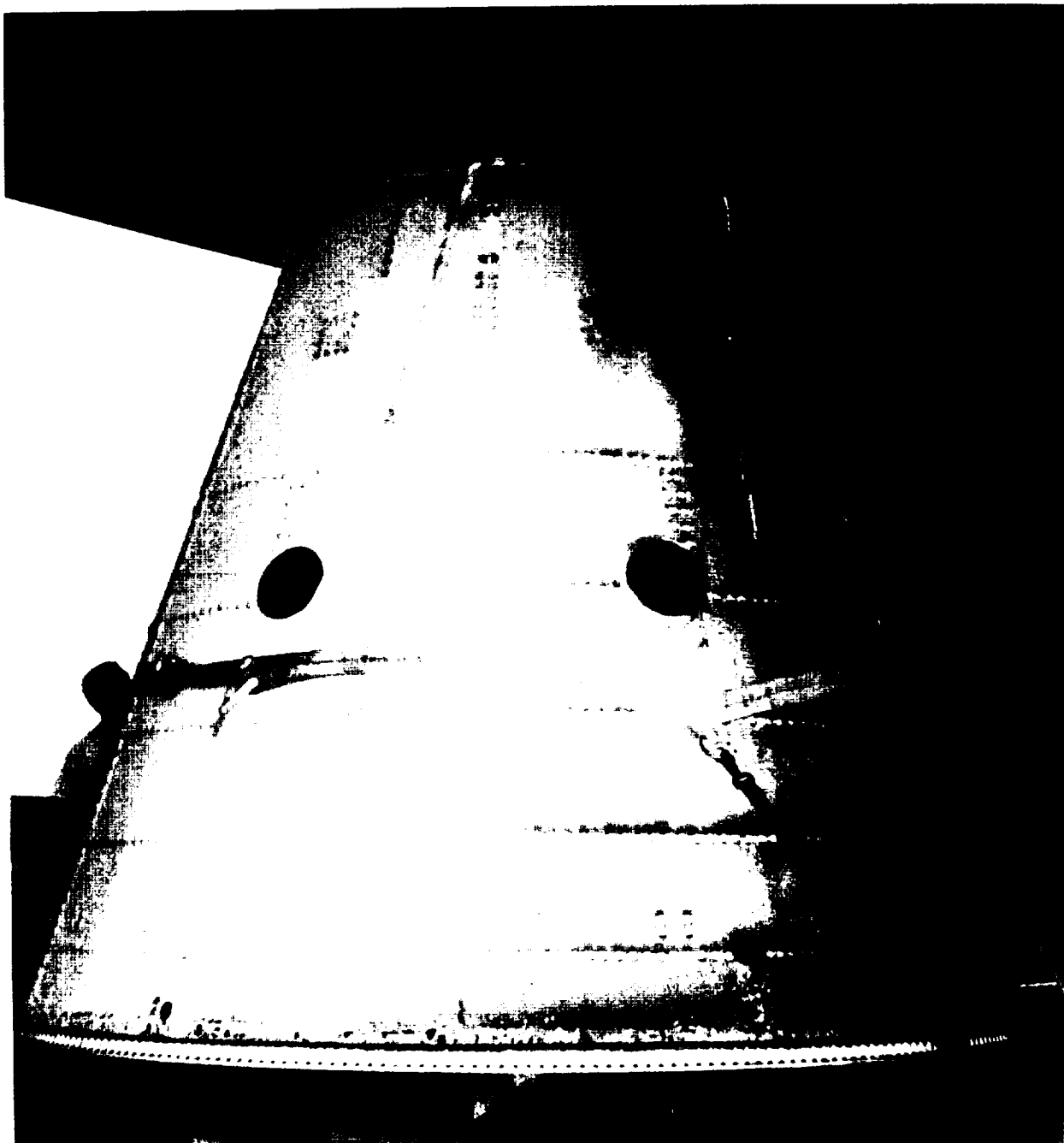


Photo 12: RH Frustum

The RH frustum was missing no TPS. The number of debonds over fasteners (24) was average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position.



Photo 13: RH Forward Skirt

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. No pins or retainer clips were missing from the frustum severance ring.

6.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The LH frustum was missing no TPS. The number of MSA-2 debonds over fasteners (28) was average (Figure 5). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position though the lower left and upper right cover attach rings had been bent by parachute entanglement.

The LH forward skirt exhibited no TPS debonds. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. No pins or retainer clips from the frustum severance ring were missing or damaged.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

Aft skirt MSA-2 was intact. More than usual amounts of foam were missing from the aft skirt aft ring. This condition was probably the result of the foam adhesion problem documented prior to launch. Launch films showed numerous light colored particles, believed to be pieces of foam, falling along side the SRB plumes during ascent.

The HDP Debris Containment Systems (DCS) appeared to have functioned properly and all the plungers were seated.

SRB Post Launch Anomalies are listed in Section 9.

STS-77 LEFT SRB FRUSTUM

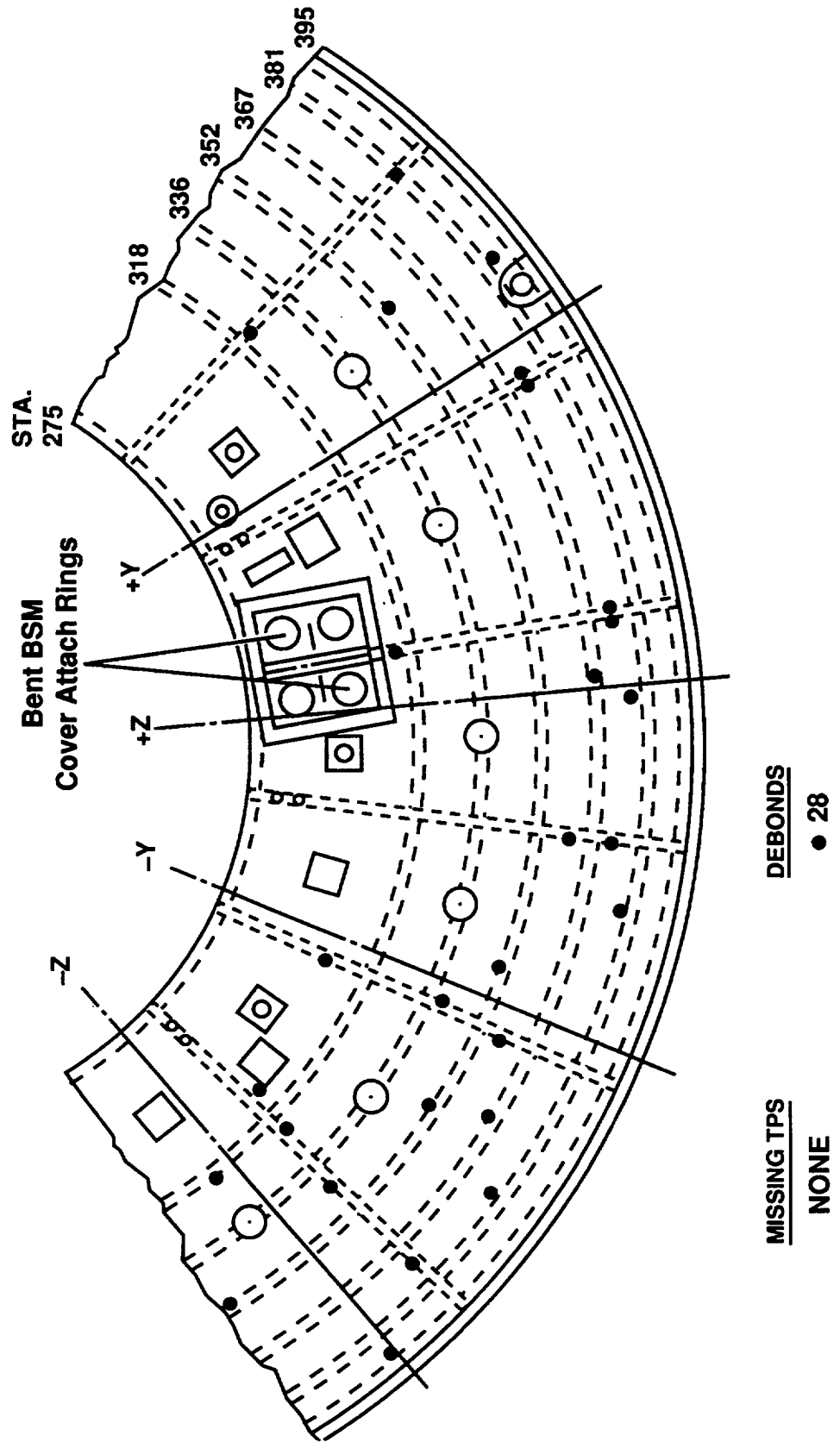


Figure 2: LH SRB Frustum

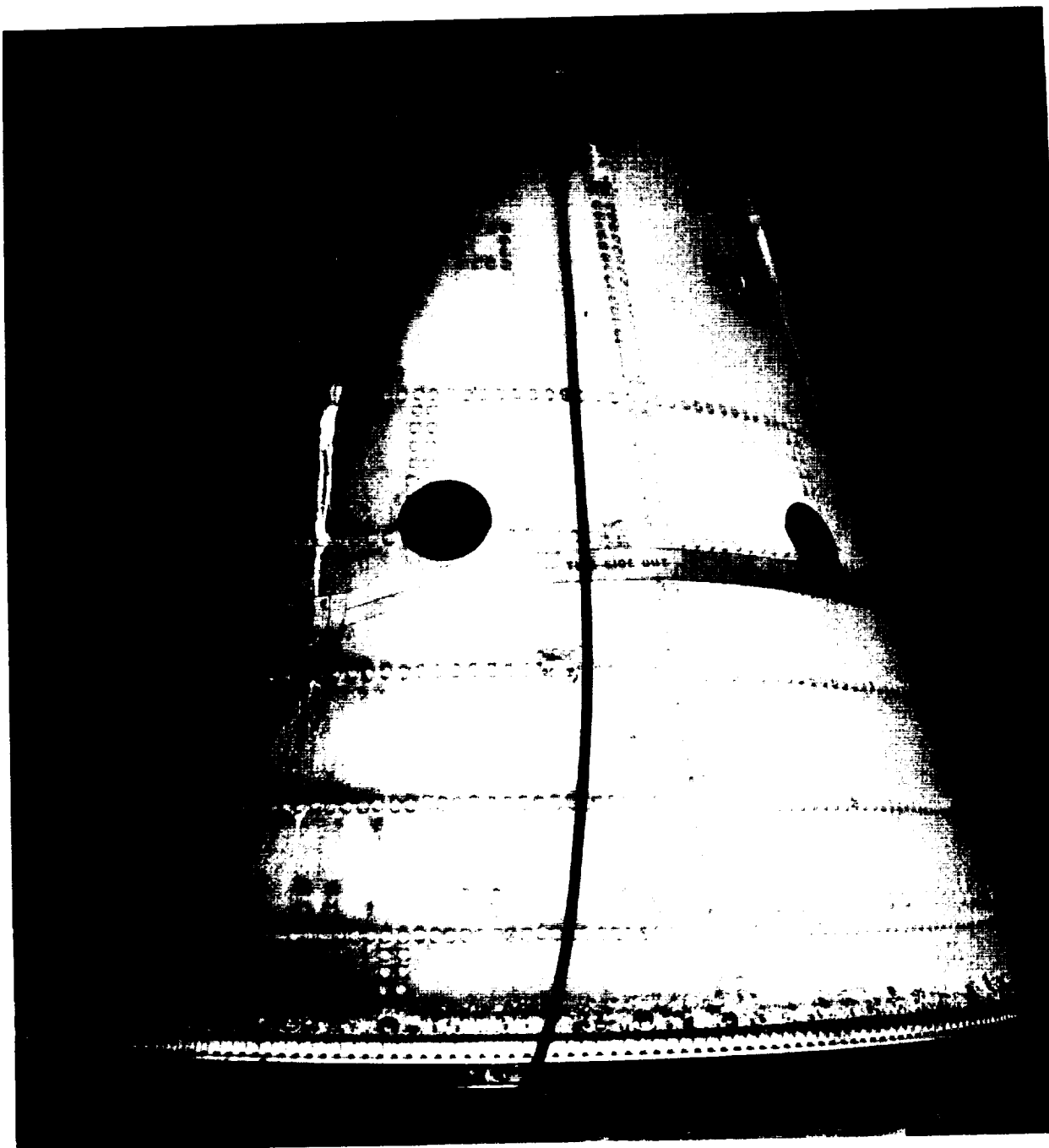


Photo 14: LH Frustum

The LH frustum was missing no TPS. The number of MSA-2 debonds over fasteners (28) was average. The BSM aero heat shield covers had locked in the fully opened position though the lower left and upper right cover attach rings had been bent by parachute riser entanglement after splashdown.



Photo 15: LH Forward Skirt

The LH forward skirt exhibited no TPS debonds. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. No pins or retainer clips from the frustum severance ring were missing or damaged.



Photo 16: LH Aft Booster/ Aft Skirt

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-105 Endeavour was conducted 29-30 May 1996 at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #3. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 81 hits, of which 17 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 61 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was less than average (reference attached figures).

The following table breaks down the STS-77 Orbiter debris damage by area:

	<u>HITS > 1</u>	<u>TOTAL HITS</u>
Lower surface	15	48
Upper surface	2	19
Right side	0	4
Left side	0	3
Right OMS Pod	0	5
Left OMS Pod	0	2
TOTALS	17	81

The largest lower surface tile damage site involved three tiles on the right chine and measured 3.5-inches long by 2.25-inches wide by 0.375-inch maximum depth. Hits on the right side along a line from nose to tail are generally attributed to ice impacts from the ET LO2 feedline bellows and support brackets.

Tile damage sites aft of the LH2 and LO2 ET/ORB umbilicals, usually caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream, were less than usual in number and size.

No tile damage from micrometeorites or on-orbit debris was identified during this inspection.

The tires and brakes were reported to be in average condition for a landing on the KSC concrete runway. Rollout with a westerly crosswind probably caused the tread undercutting on all four main landing gear tires.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. Three clips were missing from the EO-3 salad bowl fitting. All debris retention devices had closed properly and no ordnance fragments were found on the runway beneath the umbilical cavities. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

The SSME #1 and #2 Dome Mounted Heat Shield (DMHS) closeout blankets were torn at the 6:00 o'clock and 2:00-4:00 o'clock locations, respectively. The SSME #3 DMHS was in excellent condition with no missing material. Tiles on the vertical stabilizer stinger and around the drag chute door were intact and undamaged.

No ice adhered to the payload bay door. The reddish-brown discoloration on the leading edge of the LH payload bay door had not changed in appearance. No unusual tile damage was observed on the leading edges of the vertical stabilizer.

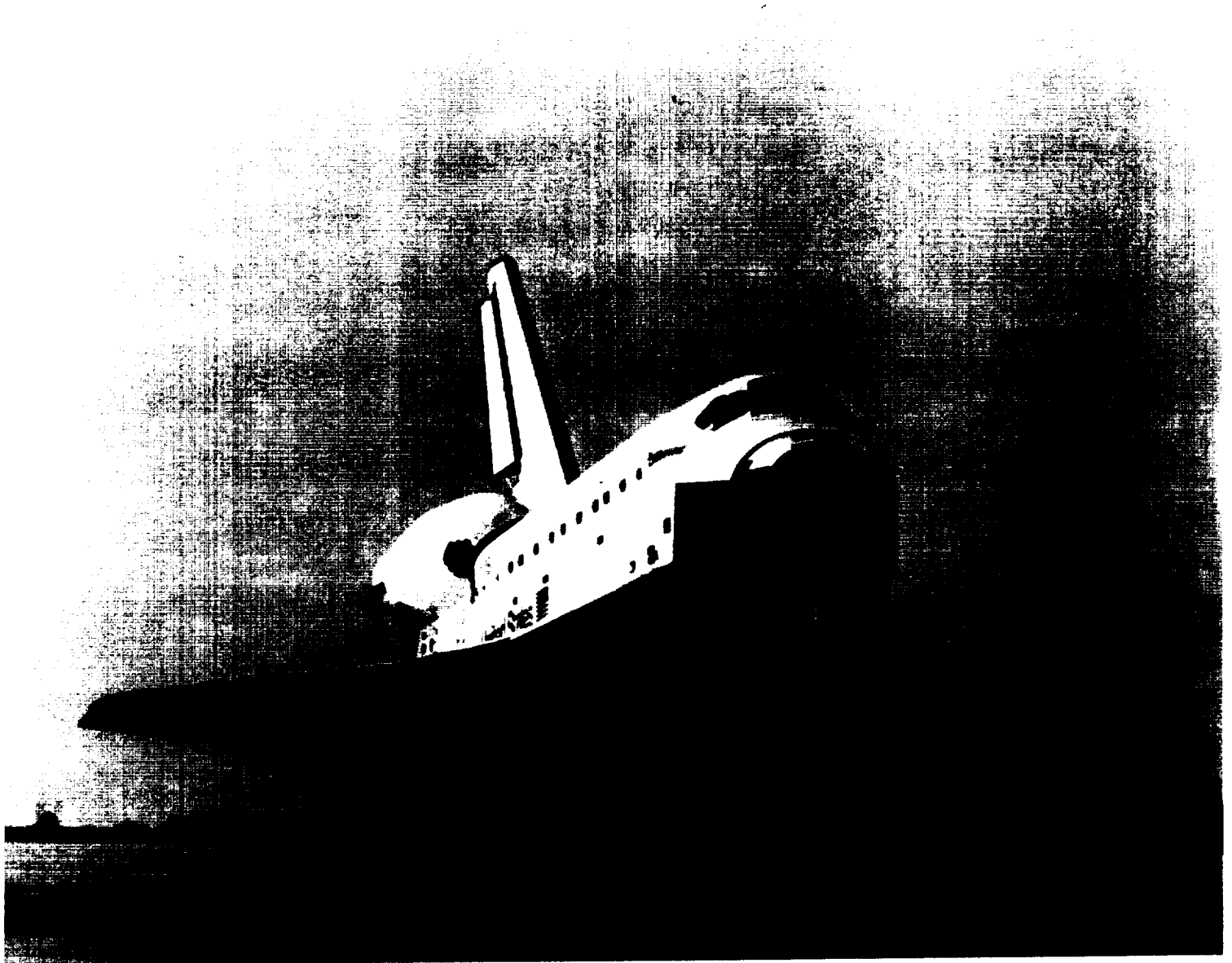


Photo 17: STS-77 Landing at KSC

Orbiter window hazing and streaking was typical. Impact damage sites on the window perimeter tiles were somewhat less than usual in number and size. Four gray TUF1 tiles had been installed in place of the black perimeter tiles above window #3 as part of a test to use densified tiles in high impact locations. The three of the four TUF1 tiles were undamaged; the fourth tile had one impact damage site that measured 0.3 in. x 0.2 in. x 0.1 in.

The post landing walkdown of Runway 33 was performed immediately after landing. No debris concerns were identified. The dead 30-inch snake on the runway was the result of aft convoy deployment and not Orbiter rollout. All drag chute hardware was recovered and appeared to have functioned normally.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was less than average when compared to previous missions (Figure 7).

Post Landing Anomalies are listed in Section 9.0.

DEBRIS DAMAGE LOCATIONS

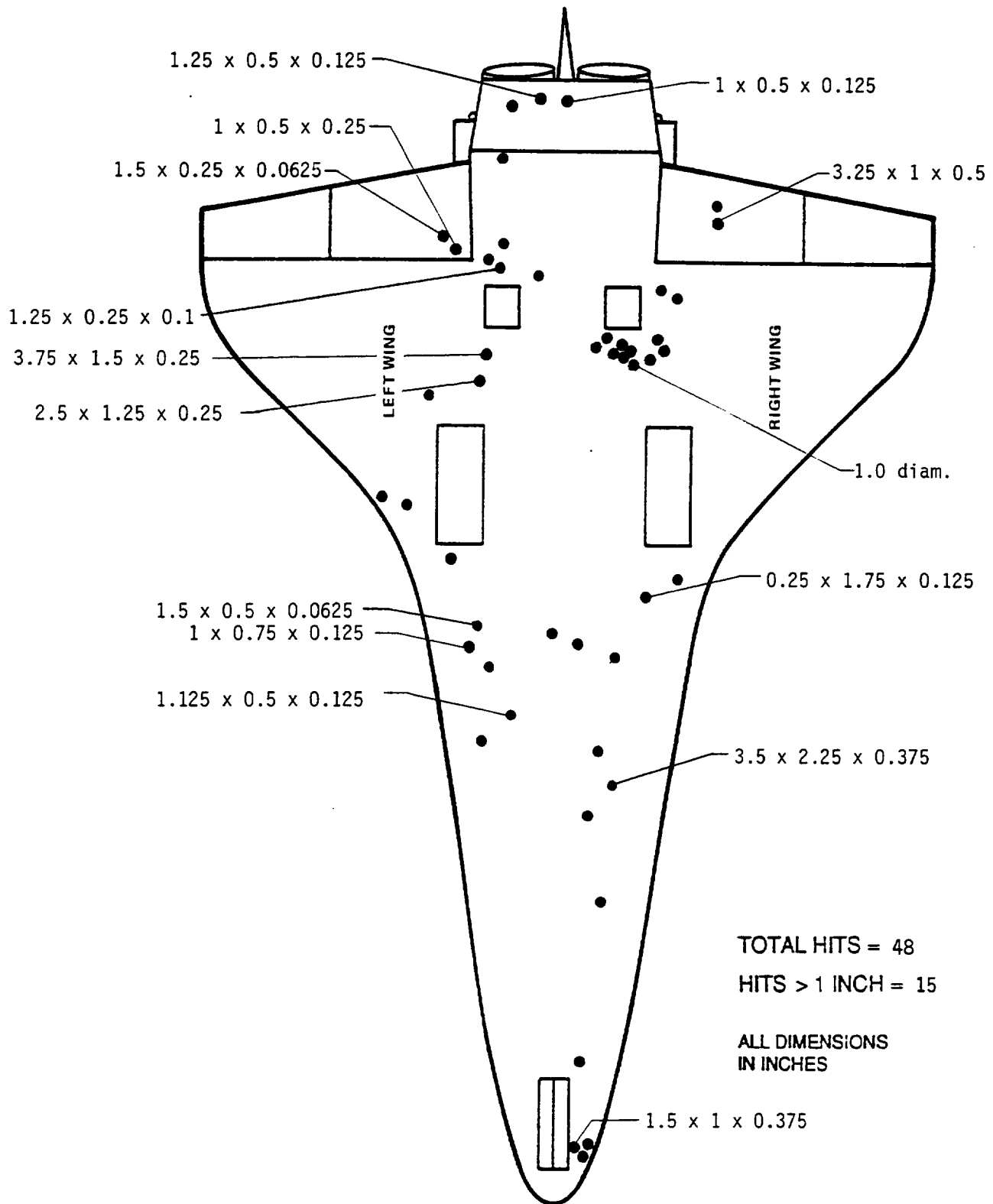


Figure 3: Orbiter Lower Surface Debris Map

DEBRIS DAMAGE LOCATIONS

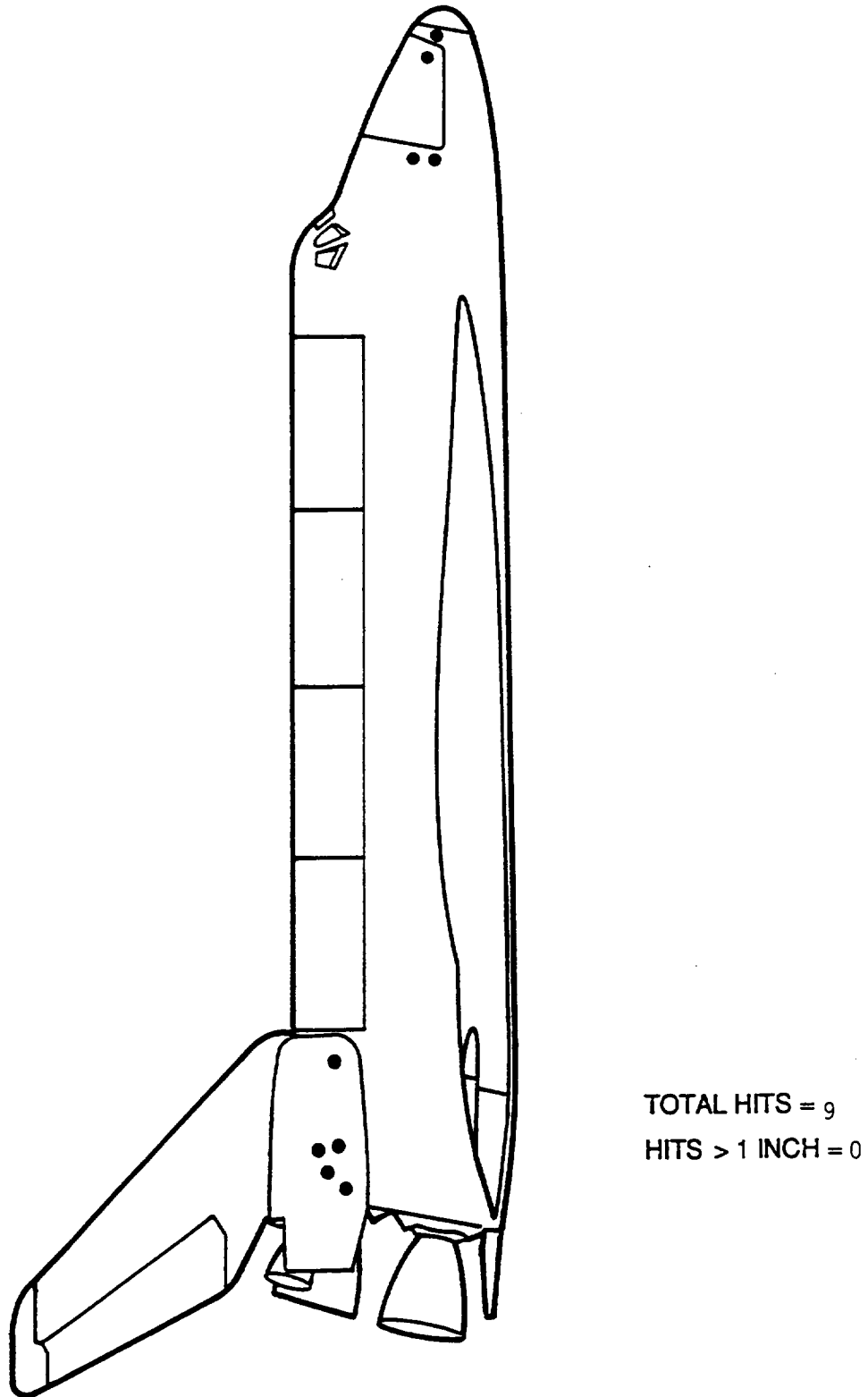


Figure 4: Orbiter Right Side Debris Map

DEBRIS DAMAGE LOCATIONS

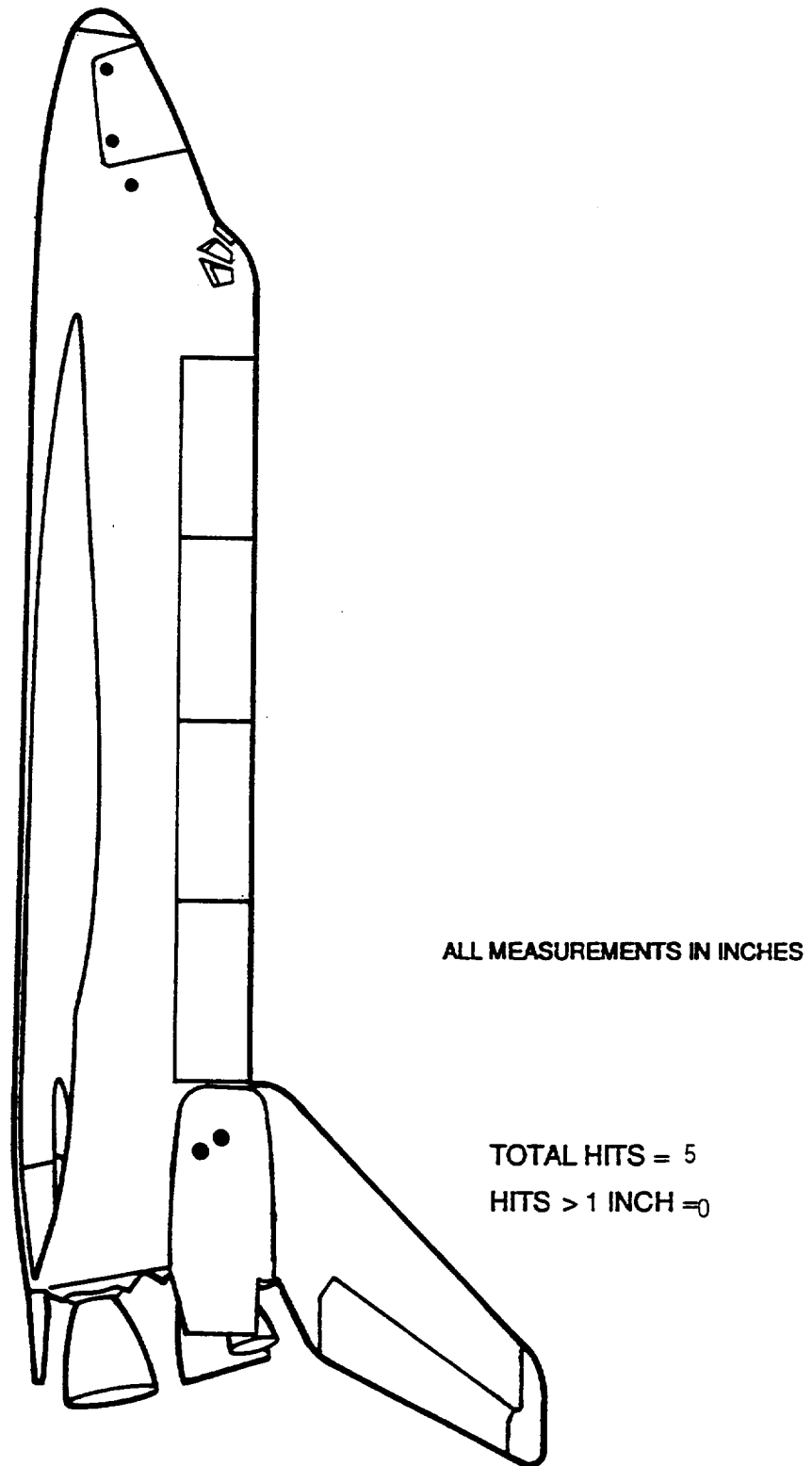


Figure 5: Orbiter Left Side Debris Map

DEBRIS DAMAGE LOCATIONS

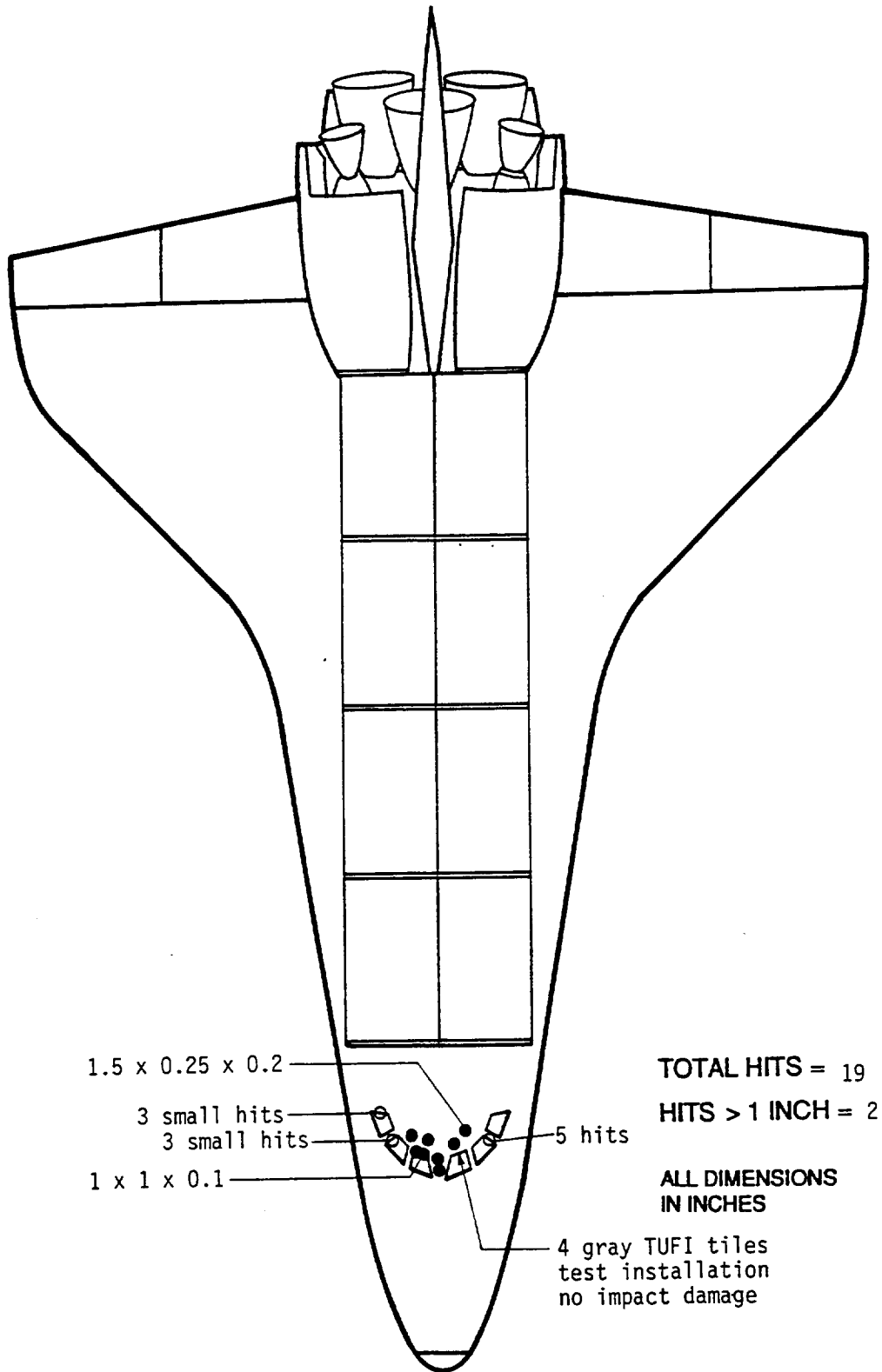


Figure 6: Orbiter Upper Surface Debris Map

ORBITER POST FLIGHT DEBRIS DAMAGE SUMMARY

	LOWER SURFACE			ENTIRE VEHICLE				LOWER SURFACE			ENTIRE VEHICLE		
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	HITS > 1 INCH	TOTAL HITS	TOTAL HITS		HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	HITS > 1 INCH	TOTAL HITS	TOTAL HITS
STS-6	21	89	36	120	154	STS-51	8	100	18	154			
STS-8	3	29	7	56	155	STS-58	23	78	26	155			
STS-9 (41-A)	9	49	14	58	120	STS-61	7	59	13	120			
STS-11 (41-B)	11	19	34	63	106	STS-60	4	48	15	106			
STS-13 (41-C)	5	27	8	36	97	STS-62	7	36	16	97			
STS-14 (41-D)	10	44	30	111	77	STS-59	10	47	19	77			
STS-17 (41-G)	25	69	36	154	151	STS-65	17	123	21	151			
STS-19 (51-A)	14	66	20	87	150	STS-64	18	116	19	150			
STS-20 (51-C)	24	67	28	81	110	STS-68	9	59	15	110			
STS-27 (51-J)	21	96	33	141	148	STS-66	22	111	28	148			
STS-28 (51-J)	7	66	17	111	125	STS-63	7	84	14	125			
STS-30 (61-A)	24	129	34	183	76	STS-67	11	47	13	76			
STS-31 (61-B)	37	177	55	257	164	STS-71	24	149	25	164			
STS-32 (61-C)	20	134	39	193	127	STS-70	5	81	9	127			
STS-29	18	100	23	132	198	STS-69	22	175	27	198			
STS-28R	13	60	20	76	147	STS-73	17	102	26	147			
STS-34	17	51	18	53	116	STS-74	17	78	21	116			
STS-33R	21	107	21	118	55	STS-72	3	23	6	55			
STS-32R	13	111	15	120	96	STS-75	11	55	17	96			
STS-36	17	61	19	81	69	STS-76	5	32	15	69			
STS-31R	13	47	14	63		AVERAGE	13.9	89.3	20.7	129.2			
STS-41	13	64	16	76		SIGMA	7.3	43.9	9.7	53.9			
STS-38	7	70	8	81		STS-77	15	48	17	81			
STS-35	15	132	17	147									
STS-37	7	91	10	113									
STS-39	14	217	16	238									
STS-40	23	153	25	197									
STS-43	24	122	25	131									
STS-48	14	100	25	182									
STS-44	6	74	9	101									
STS-45	18	122	22	172									
STS-49	6	55	11	114									
STS-50	28	141	45	184									
STS-46	11	186	22	236									
STS-47	3	48	11	108									
STS-52	6	152	16	290									
STS-53	11	145	23	240									
STS-54	14	80	14	131									
STS-56	18	94	36	156									
STS-55	10	128	13	143									
STS-57	10	75	12	106									

MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSIS
SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 7: Orbiter Post Flight Debris Damage Summary

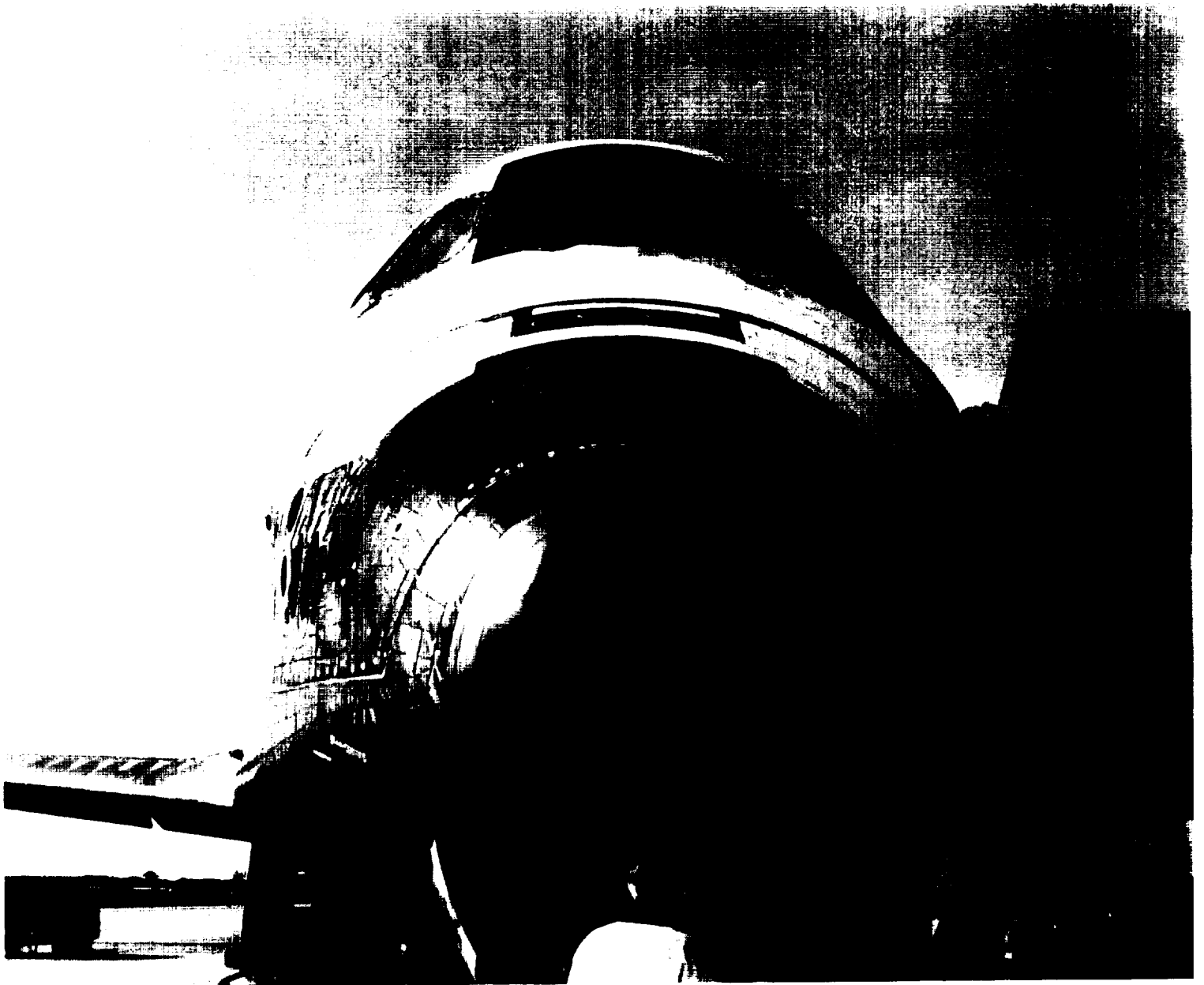


Photo 18: Overall View of Orbiter Nose



Photo 19: Overall View of Orbiter Right Side



Photo 20: Overall View of Orbiter Left Side



Photo 21: Overall View of Orbiter Base Heat Shield/SSMEs



Photo 22: Orbiter Windows 1 - 3

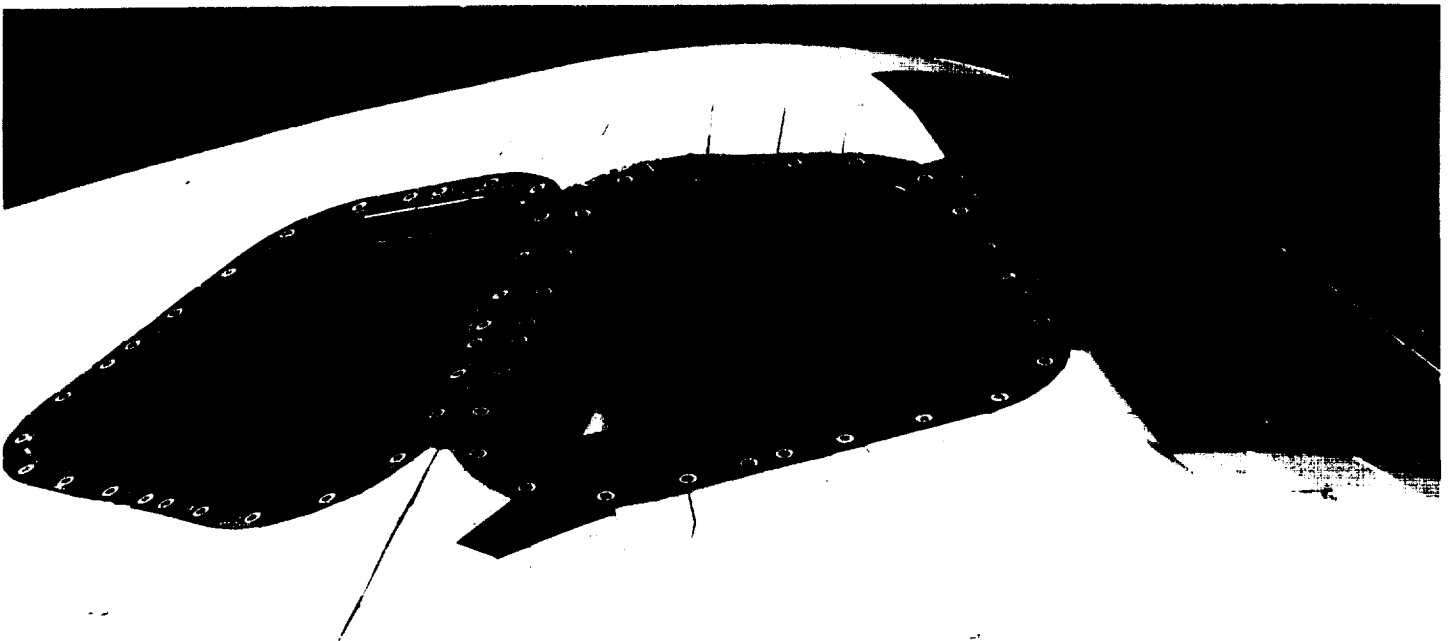


Photo 23: Orbiter Windows 4 - 6

Orbiter window hazing and streaking was typical. Impact damage sites on the window perimeter tiles were somewhat less than usual in number and size. Four gray TUFIT tiles had been installed in place of the black perimeter tiles above window #3 as part of a test to use densified tiles in high impact locations. The three of the four TUFIT tiles were undamaged; the fourth tile had one impact damage site.



Photo 24: Lower Surface Tile Damage

The Orbiter lower surface sustained a total of 32 hits, of which 5 had a major dimension of 1-inch or larger.

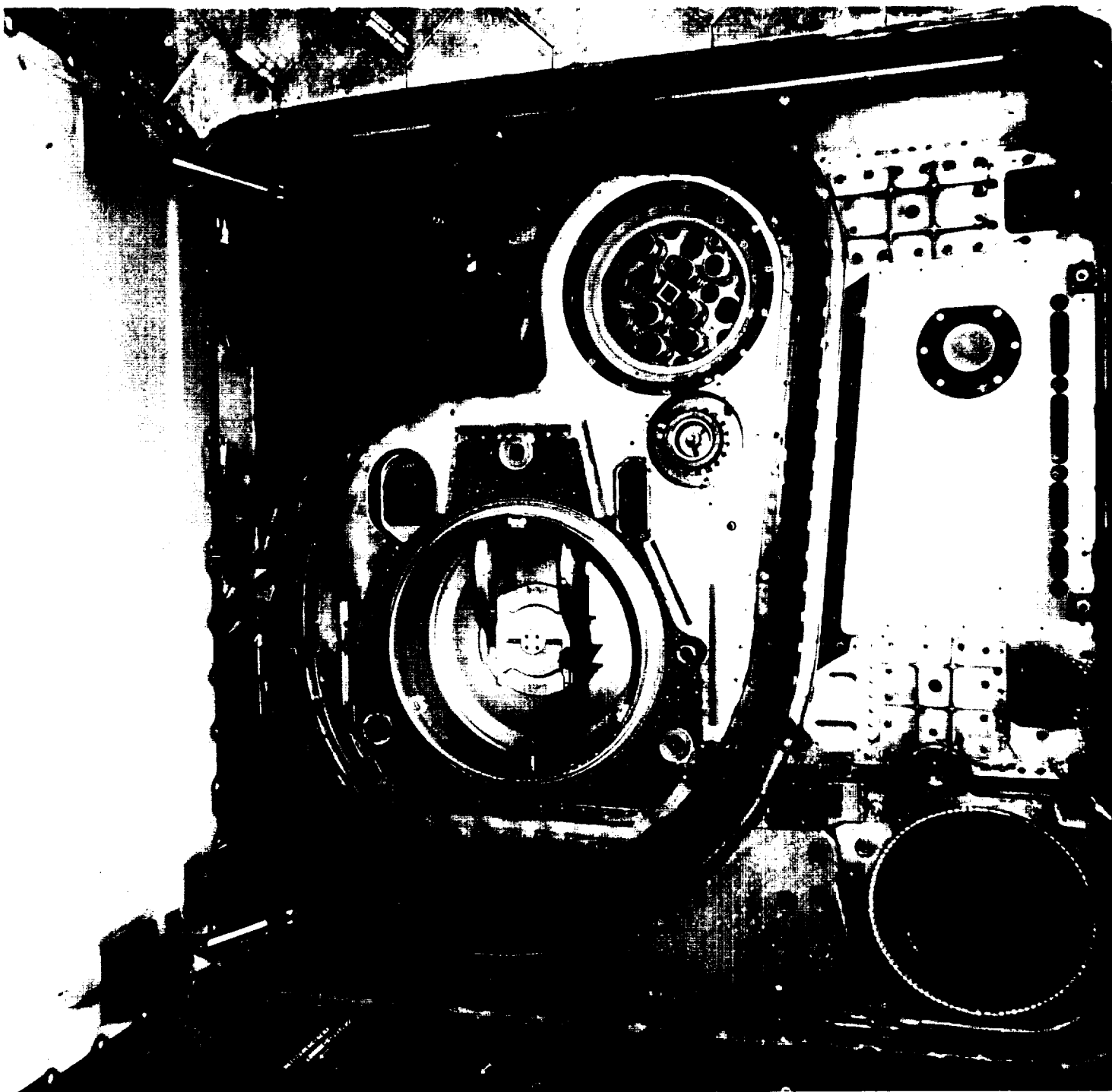


Photo 25: LO2 ET/ORB Umbilical

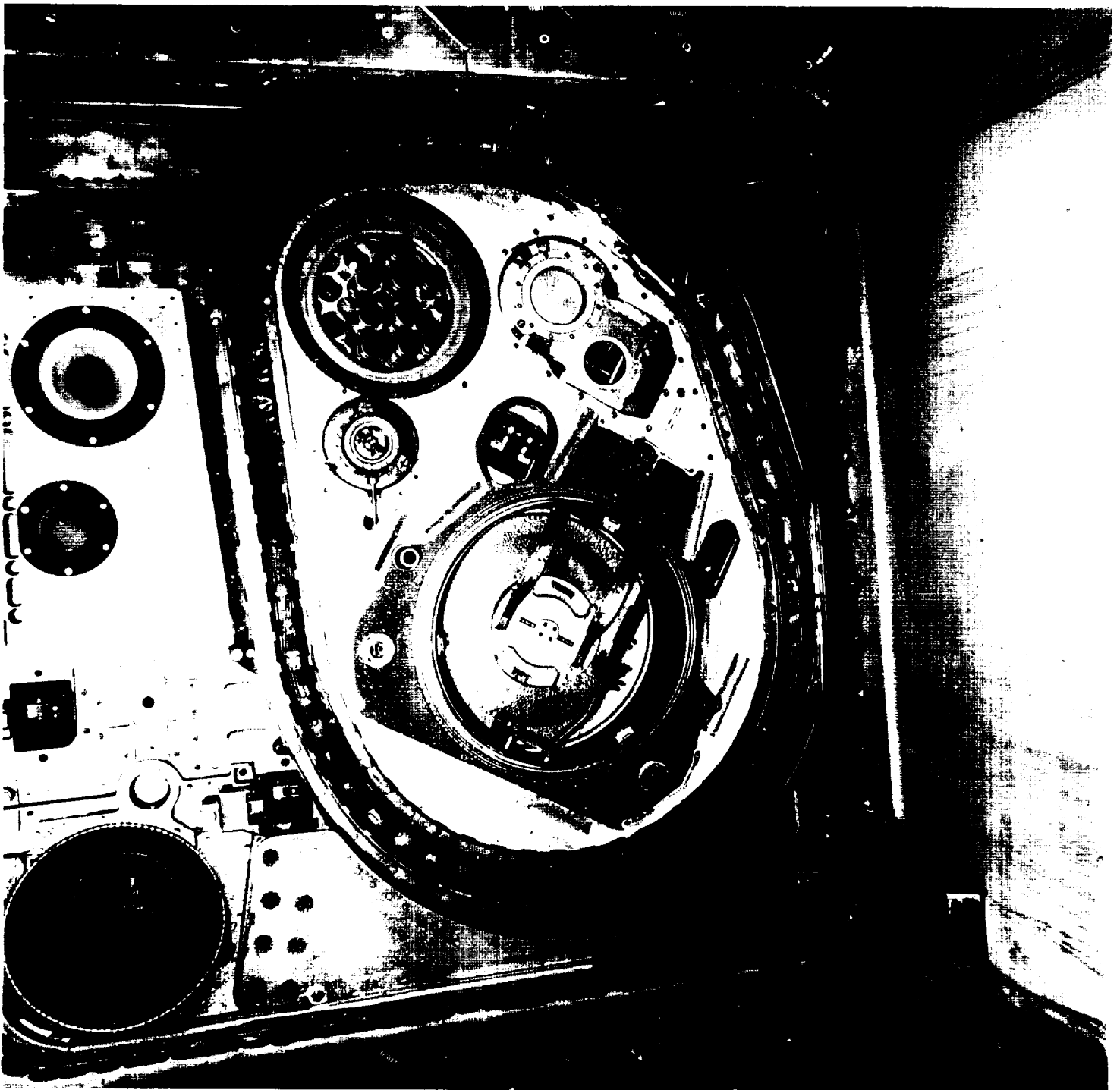


Photo 26: LH2 ET/ORB Umbilical

8.0 DEBRIS SAMPLE LAB REPORTS

A total of eight samples were obtained from OV-105 Endeavour during the STS-77 post landing debris assessment at Kennedy Space Center. The submitted samples consisted of 8 wipes from Orbiter windows #1-8. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves both the placing and the correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results/analyses are listed by Orbiter location in the following summaries.

8.1 ORBITER WINDOWS

Samples from the Orbiter windows indicated exposure to facility environment, SRB BSM exhaust (as metallic particulate), landing site materials (as earth minerals), Orbiter Thermal Protection System (as tile, tile repair, and glass insulation), building type insulation, paints and primer from various sources. There was no apparent vehicle damage related to these residuals.

8.2 ORGANIC ANALYSIS

The results of the STS-77 organic analysis are pending.

8.3 NEW FINDINGS

This set of post-flight debris residual samples provided no new findings. The variety of residual material continues to be representative of that documented in previous mission sampling (reference Figure 8 for STS-77).

STS	Windows	Sample Location		
		Wing RCC	Lower Tile Surface	Umbilical
77	Metallics - Fac. Env./BSM Residue(SRB) Tile, Tile repair (ORB TPS) Insulation Glass(ORB TPS) Building type insulation Earth Minerals Organics Paints and primer			
76	Metallics - Fac. Env./BSM Residue(SRB) Tile repair (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics Window polish residue Paint and primer Carbon black/copper alloy			
75	Metallics - Fac. Env./BSM Residue(SRB) Tile repair (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics - Plastics, cellulosic Window polish residue Paint and primer			
72	Metallics - Fac. Env./BSM Residue(SRB) RTV, Tile, Tile repair (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics - Plastics, cellulosic Window polish residue Paint and primer			Pre-launch Window Cover: Metallic-Fac.Env.;RTV, Tile-(TPS) Insulation Glass - (ORB TPS) Earth Minerals; Organics--phenolic, urethane, isocyanurate foam Pre-launch Window: Metallic - Fac.Env.;Window polish re RTV, Tile, Tile repair, ins glass (TPS); Earth Minerals, Paint/primer;Organics phenolic, urethane, isocyanurate foam
74	Metallics - Fac. Env./BSM Residue(SRB) RTV (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics - Plastic polymers, sealant, RTV(RCS thruster nozzle cover adhesive) SRB sealant Paint and primer			

For data on previous missions refer to mission report STS-75

Figure 8: Orbiter Post Landing Microchemical Sample Results

9.0 POST LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, 8 post launch anomalies, but no In-Flight Anomalies (IFAs), were observed on the STS-77 mission.

9.1 LAUNCH PAD/SHUTTLE LANDING FACILITY

1. A piece of bolt 1-1/4 inch by 7/8 inch diameter was found on top of the HDP #2 stud.
2. A piece of foam, approximately 2-inches long by 1.5-inches wide, was torn loose by GUCP retraction from the adjacent -Z stringer.

9.2 SOLID ROCKET BOOSTERS

1. More than usual amounts of foam were missing from the aft rings. Launch films showed numerous, small light-colored particles, believed to be pieces of foam, falling along side the SRB plumes during ascent.

9.3 EXTERNAL TANK

1. Part of the +Y bipod jack pad closeout (4-inches long by 4-inches wide) was missing. The resulting divot went to substrate and exposed primer. Similarly, a 4-inch long by 3-inch wide divot to substrate was centered between the bipods in the LH2 tank-to-intertank flange closeout. Loss of this TPS in flight most likely contributed to the number of Orbiter lower surface tile damage sites greater than 1-inch in size.
2. Approximately 30 small, shallow divots occurred in intertank stringer valleys in an area around the -Y bipod spindle housing closeout/ramp. Approximately 10 similar divots were located around the +Y bipod ramp and 4 shallow divots were visible in the LH2 tank acreage just aft of the -Y bipod.
3. Missing foam from the forward inboard corner of the pressurization line ice/frost ramp at XT-1464 revealed substrate primer. The divot was approximately 4-inches long by 2-inches wide.
4. A divot in the -Y thrust strut flange closeout was estimated to be 12 inches long by 4 inches wide by 1 inch deep. Erosion of the +Y flange closeout was visible.

9.4 ORBITER

1. The largest lower surface tile damage site involved three tiles on the right chine and measured 3.5-inches long by 2.25-inches wide by 0.375-inch maximum depth. Hits on the right side along a line from nose to tail are generally attributed to ice impacts from the ET LO2 feedline bellows and support brackets.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

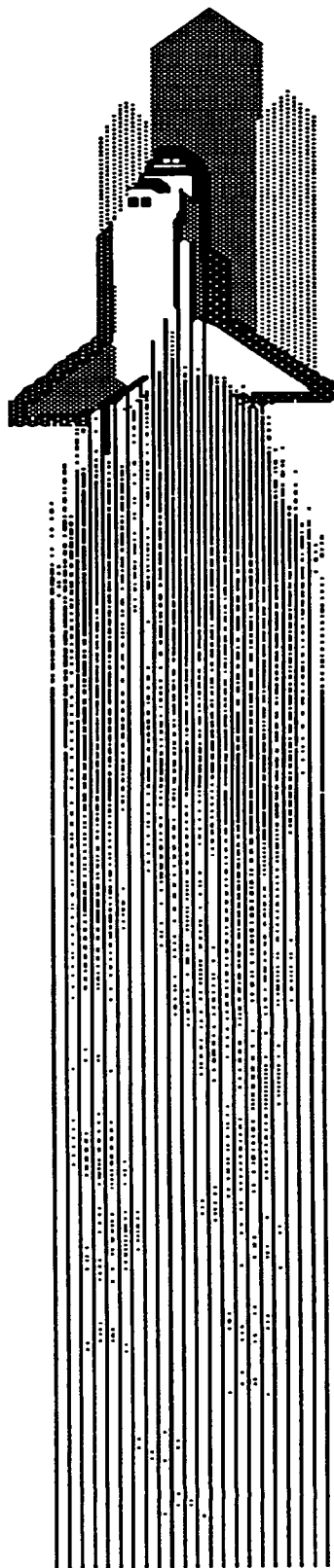
Space Shuttle

Earth Science Branch

**Image Science and
Analysis Group**

STS-77 Summary of Significant Events

June 28, 1996



Space Shuttle Image Science and Analysis Group


STS-77 Summary of Significant Events


Project Work Order - SN-5CR


Approved By

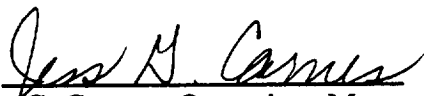
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NASA

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1. STS-77 (OV-105): Film/Video Screening and Timing Summary

1. STS-77 (OV-105): FILM / VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-77 launch of Endeavour (OV-105) from pad B occurred on Sunday, May 19, 1996, (day 140) 10:30:00.016 Coordinated Universal Time (UTC) as seen on camera E9. Solid Rocket Booster (SRB) separation occurred at 10:32:04.242 UTC as seen on camera KTV4B.

On launch day, 24 of 24 expected videos were received and screened. Following launch day, 43 films were screened. No potential anomalies were observed during launch.

Detailed Test Objective 312, photography of SRB separation and the external tank after separation, was performed using the Orbiter umbilical well cameras (method 1). Handheld photography of the ET was acquired using the Nikon F4 with the 300mm lens and 2x converter (method 3).

1.1.2 Landing

Endeavour landed on runway 33 at KSC Shuttle Landing Facility on May 29, 1996. Eleven of twelve expected videos were received. Nine films of the Orbiter's approach and landing were received.

No major anomalies were noted in the approach, landing, or roll-out video views screened. The drag chute deployment appeared normal.

1.2 TIMING ACTIVITIES

Launch:

The time codes from videos and films were used to identify specific events during the initial screening process.

Video cameras: ET204, ET207, ET208, ET212, ET213, KTV2, KTV5, KTV13, KTV4B, KTV7B, KTV11B, KTV21B, OTV150, OTV160, OTV109, OTV141, OTV148, OTV149, OTV151, OTV154, OTV161, OTV163, OTV170, OTV171 had IRIG timing.

Film cameras: E31, E41, E205, E207, E208, E212, E213, E220, and E223 had IRIG timing. E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15, E16, E17, E18, E19, E20, E31, E33, E34, E36, E40, E52, E54, E57, E59, E60, E62, E63, E76, E77, E222, and E224 had in-frame alphanumeric timing.

1. STS-77 (OV-105): Film/Video Screening and Timing Summary

Landing:

Video cameras: The eleven videos screened on landing day (EL17IR, EL18IR, KTV5L, KTV6L, KTV11L, KTV12L, KTV13L, KTV15L, KTV20L, KTV33L, and SLF North) had IRIG timing.

Film cameras: The nine film cameras of landing (EL1, EL2, EL4, EL7, EL9, EL10, EL15, EL30, and EL31) had in-frame alphanumeric timing.

The landing and drag chute event times are provided in Table 1.2.

Event Description	Time (UTC)	Camera
Landing Gear - Doors Opened	150:11:09:02.813	KTV6L
Left Main Wheel Touchdown	150:11:09:18.762	KTV6L
Right Main Wheel Touchdown	150:11:09:18.829	KTV6L
Drag Chute Initiation	150:11:09:26.836	KTV11L
Pilot Chute at Full Inflation	150:11:09:27.773	KTV33L
Bag Release	150:11:09:28.424	KTV33L
Drag Chute Inflation in Reefed Configuration	150:11:09:29.558	KTV33L
Drag Chute Inflation in Disreefed Configuration	150:11:09:32.728	KTV33L
Nose Wheel Touchdown	150:11:09:34.229	KTV33L
Drag Chute Release	150:11:09:55.918	KTV33L
Wheel Stop	150:11:10:10.888	KTV15L

Table 1.2 Landing Video Timing Events

2. Summary of Significant Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS

2.1.1 Debris Near the Time of SSME Ignition

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition. Most of the debris was umbilical ice and RCS paper. No follow-up action was requested.

2.1.1.1 Debris Strikes Umbilical Door

(Camera: OTV109)

Several pieces of debris (probable ice debris) fell from the ET/Orbiter umbilicals and contacted the umbilical door sill at SSME ignition. No tile damage was seen. Debris contacting the umbilical door sill has been seen on previous missions. No follow-up action was requested.

2.1.1.2 Debris Strikes SSME #3

(Camera: OTV170)

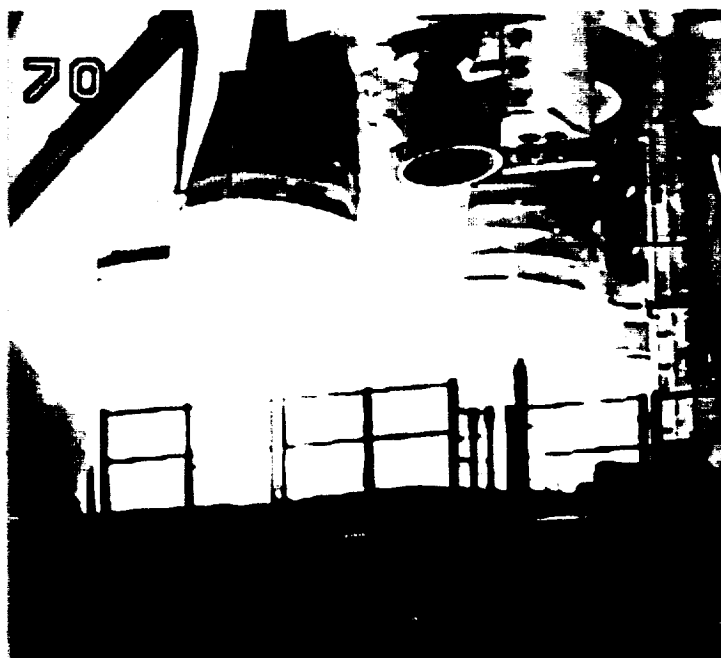


Figure 2.1.1.2 Debris Strikes SSME #3

Three white-colored pieces of debris (probably ice) from the LO2 TSM disconnect contacted the SSME #3 engine bell prior to lift-off (10:29:57.746 UTC). No damage to the engine bell was seen. No follow-up action was requested.

2. Summary of Significant Events

2.1.1.3 Debris Seen Near Body Flap

(Camera: OTV163)

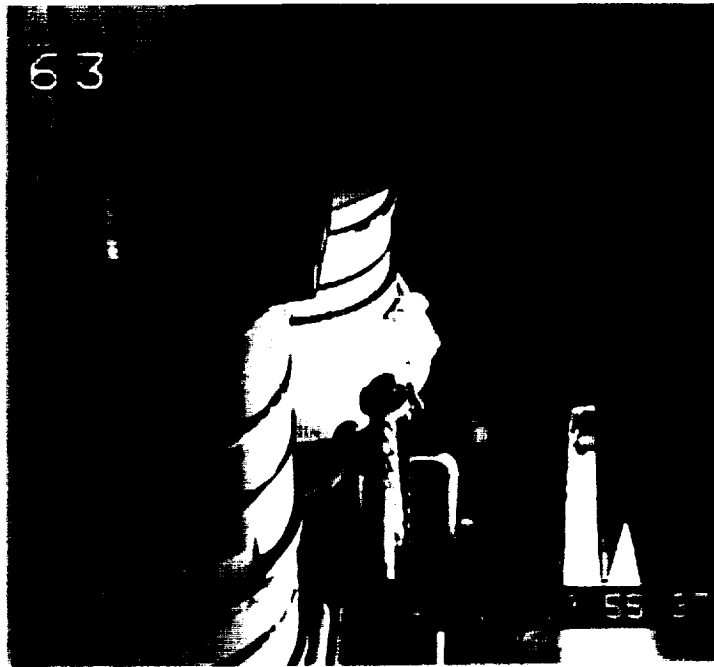


Figure 2.1.1.3 Debris Seen Near Body Flap

A single light-colored piece of debris was seen traveling under the body flap from the +Z side of the Orbiter and struck the MLP deck during SSME ignition (10:29:55.377 UTC). The source of the debris was not determined. The debris was not seen to contact the launch vehicle. No follow-up action was requested.

2.1.1.4 Rectangular Debris Falls Along Body Flap

(Camera: E16)

A rectangular-shaped, white piece of debris (possible ET/Orbiter umbilical ice) fell along the body flap at SSME ignition. No follow-up action was requested.

2.1.2 Debris Near the Time of SRB Ignition

As on previous missions, multiple pieces of debris were seen near the time of SRB ignition. No follow-up action was requested.

2.1.2.1 Small Dark Debris Near RSRB at Liftoff

(Cameras: E8, E9)

Two pieces of small dark debris were seen near the RSRB holddown posts M-1 and M-2 at SRB ignition (10:30:00.018 UTC). The debris near holddown post M-2 was first seen near the debris containment system (DCS). Neither piece of debris was seen to contact the launch vehicle. No follow-up action was requested.

2. Summary of Significant Events

2.1.2.2 Rope-Shaped Debris Seen Near the Left Inboard Elevon (Camera: E18)

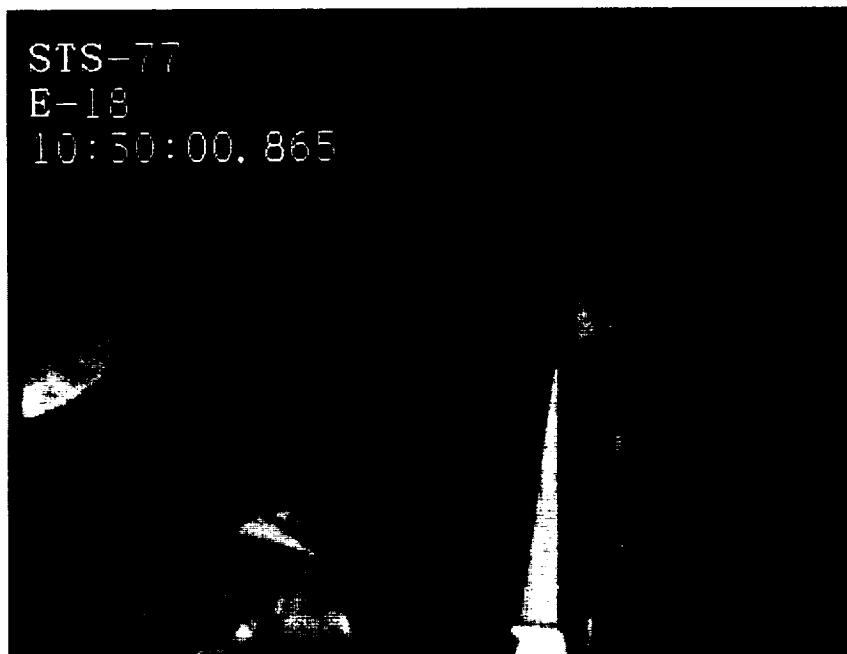


Figure 2.1.2.2 Rope-Shaped Debris Seen Near the Left Inboard Elevon

A piece of rope-shaped debris was seen to travel from near the -Z side of the left inboard elevon toward the LH2 TSM and SSME #2 during liftoff (10:30:00.865 UTC). This debris was not seen to contact the launch vehicle. No follow-up action was requested.

2.1.2.3 Rope-Shaped Debris Seen Near Holddown Post M-4 (Cameras: E7, E15)

A piece of rope-shaped water baffle debris was seen near the RSRB holddown post M-4 at liftoff (10:30:00.895 UTC). No follow-up action was requested.

2. Summary of Significant Events

2.1.2.4 Flame Duct Debris (Camera: E222, E224)



Figure 2.1.2.4 Flame Duct Debris

Multiple pieces of SRB flame duct debris were noted north of the vehicle during liftoff (10:30:01.430 UTC). The debris was not seen to contact the vehicle. No follow-up action was requested.

2.1.3 Debris After Liftoff

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) after liftoff on the launch tracking views. The debris was probably reaction control system (RCS) paper and ice from the ET/Orbiter umbilicals. None of the debris was seen to contact the launch vehicle. No follow-up action was requested.

2.1.3.1 Debris Falls from ET/Orbiter Umbilicals During Liftoff (Camera: OTV161)

Ice debris was seen falling aft from the ET/Orbiter umbilicals during liftoff (10:30:04.453 UTC). No damage to the launch vehicle was seen. No follow-up action was requested.

2.1.3.2 A Single Large Light-Colored Piece of Debris Seen Near SSME's (Camera: E52)

A single, large light-colored piece of debris fell from the SSMEs into the SRB exhaust plume at 10:30:08.000 UTC. No follow-up action was requested.

2. Summary of Significant Events

2.1.3.3 Orange Debris Seen in SRB Exhaust

(Camera: E57)

Bright, orange-colored debris (possible burning SRB propellant or aft skirt instafoam) was seen in the SRB exhaust cloud during early ascent (10:30:14.092 UTC). No follow-up action was requested.

2.1.3.4 Debris Seen Near Starboard Wing

(Camera: E54)

A single, large light-colored piece of debris first noted aft of the right wing fell into SRB plume at 10:30:20.844 UTC. No follow-up action was requested.

2.1.3.5 Debris Seen aft of SSME's during Ascent

(Camera: ET212)

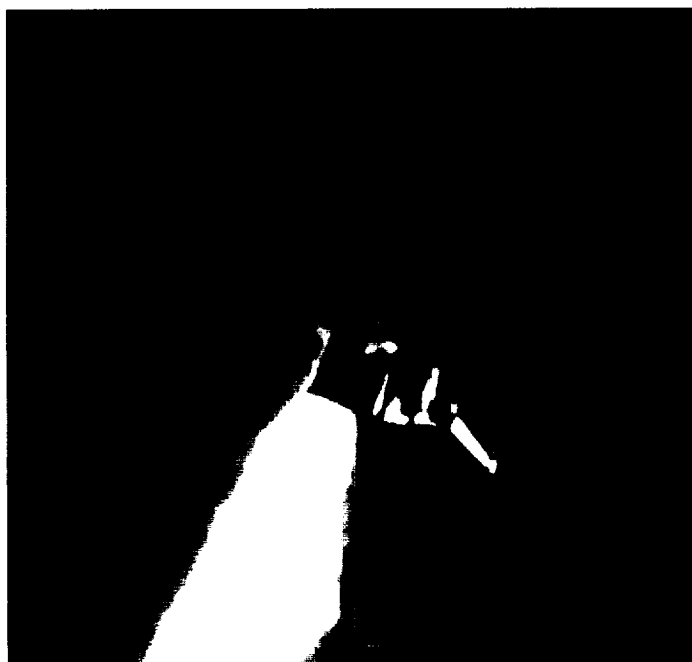


Figure 2.1.3.5 Debris Seen Aft of SSME's during Ascent

A single piece of light-colored debris was seen aft of the SSME's during ascent (10:30:28.864 UTC). Debris aft of the SSME's during ascent has been seen on previous missions. No follow-up action was requested.

2. Summary of Significant Events

2.1.3.6 Multiple Pieces of Light-Colored Debris (Cameras: E207, E213, E222)



Figure 2.1.3.6 Multiple Pieces of Light-Colored Debris

Multiple pieces of light-colored debris (approximately 7 pieces), first seen behind the body flap, fell aft of the SLV between 15 and 34 seconds MET. No follow-up action was requested.

2. Summary of Significant Events

2.1.3.7 Debris Seen Along SRB Exhaust Plume

(Cameras: KTV4B, KTV13, ET207, ET208, E205)

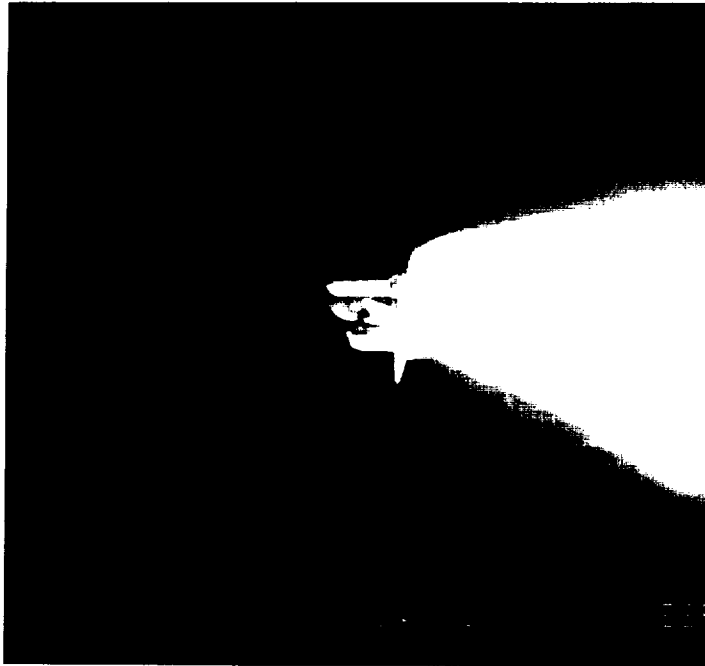


Figure 2.1.3.7 Debris Seen Along SRB Exhaust Plume

Debris was seen falling along the SRB exhaust plume during ascent (10:31:14.492, 10:31:15.253, 10:31:20.525, and 10:31:21.159 UTC). Also, debris (probably slag) was seen near the SRB exhaust plume just prior to SRB separation (10:32:03.134, 10:32:03.339 UTC). Debris near the SRB exhaust plumes has been seen on previous missions. No follow-up action was requested.

2. Summary of Significant Events

2.2 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.2.1 Orange Vapor and Flashes Seen During SSME Ignition

(Cameras: E2, E4, E5, E15, E16, E17, E18, E20, E36, OTV151, OTV163, OTV170, OTV171)



Figure 2.2.1 Orange Vapor and Flashes Seen During SSME Ignition

Several white flashes of vapor were seen forward of the rims of the SSME's during SSME ignition (10:29:56.495, 10:29:56.575 UTC). Also, orange vapor (probable free burning hydrogen) was seen above the rims of the SSME's and behind the body flap, and near the base of the vertical stabilizer during the engine start-up (10:29:54.8 UTC). Orange vapors have been seen on previous missions. No follow-up action was requested.

2.2.2 SSME Mach Diamond Formation

(Camera: E19, E20, E76)

The SSME Mach diamonds formed out of sequence. The SSME #2 Mach diamond was seen to form 0.063 seconds prior to the SSME #3 Mach diamond. The times of the Mach diamond formation were:

SSME #2 Mach diamond formation	10:29:56.886 UTC
SSME #3 Mach diamond formation	10:29:56.949 UTC
SSME #1 Mach diamond formation	10:29:57.026 UTC

2. Summary of Significant Events

2.2.3 TPS Erosion on Base Heat Shield

(Camera: E19)

A small area of TPS erosion was seen on the base heat shield near SSME #2 during the main engine start-up (10:29:56.388 UTC). TPS erosion on the base heat shield has been seen on previous missions. No follow-up action was requested.

2.2.4 TPS Erosion on the ET GH2 Disconnect Area

(Camera: E33)

Slight TPS erosion was noted on the ET GH2 disconnect area after vent arm retraction. No follow-up action was requested.

2.2.5 Vapor from GH2 Vent Arm Port

(Camera: E59)

Vapors were seen coming from the external tank GH2 vent arm port during liftoff. Vapor from the ET GH2 vent arm port has been seen on previous missions. No follow-up action was requested.

2.3 ASCENT EVENTS

2.3.1 Vapor Seen Near -Z Side of ET after the Roll Maneuver

(Camera: E224)

Light-colored vapor was seen along -Z side of the ET after the roll maneuver. No follow-up action was requested.

2. Summary of Significant Events

2.3.2 Flares in SSME Exhaust Plume

(Cameras: KTV13, KTV21, E208, E205, E212, ET208, ET212)



Figure 2.3.2 Flare in SSME Exhaust Plume

Several orange-colored flares were seen in the SSME exhaust plume during early ascent. Flares in the SSME exhaust plume have been seen on previous missions. No follow-up action was requested.

2. Summary of Significant Events

2.4 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (DTO-312)

2.4.1 Analysis of the Umbilical Well Camera Films (Task #2)

Three rolls of STS-77 umbilical well camera film were acquired: the 16mm film (5 mm lens) and the 16mm film (10mm lens) from the LH2 umbilical, and the 35mm film from the LO2 umbilical. The +X translation maneuver was performed on STS-77.

Good coverage of the LSRB separation was acquired. As on previous missions, numerous light-colored pieces of debris (probably insulation) and dark debris (probably charred insulation) were seen throughout the SRB film sequence. Typical ablation and charring of the LH2 umbilical electric cable tray and the -Y ET/SRB vertical strut were seen. Two dark-colored pieces of debris (probably TPS material) traveled in front of the left SRB. The debris did not appear to strike the vehicle.



Figure 2.4.1 (A) LH2 ET/Orbiter Umbilical

Good coverage of the external tank separation was acquired. The frozen hydrogen visible on the face of the LH2 ET/Orbiter umbilical is typical of that seen on previous missions (1). TPS ablation was noted on the lower +Z axis of the ET forward of the left SRB/ET aft attach structure (2). The large mark visible on the ET aft dome under the aft attach structure was present prior to launch (3). A divot was visible on the -Y thrust strut flange. The charring of the ET aft dome (caused by aero-heating during ascent) is typical of previous missions. Numerous light-colored pieces of debris (probably insulation or frozen hydrogen) were seen through out the ET separation sequence.

2. Summary of Significant Events



Figure 2.4.1 (B) LO2 ET/Orbiter Umbilical

The LO2 ET/Orbiter forward umbilical lightning contact strip was missing (1). Missing lightning contact strips have been seen on previous missions and has been listed as an in-flight anomaly (IFA). TPS erosion is visible on the LO2 electric cable tray (2). TPS erosion was noted on the +Y thrust strut flange.

2. Summary of Significant Events



Figure 2.4.1 (C) ET LH2 Tank/Intertank

A portion of the +Y bipod jack-pad closeout was missing exposing the substrate (1). A similar appearing divot was centered between the bipod legs on the LH2 tank-to-intertank flange (2). Multiple small, shallow-appearing, divots occurred in the intertank stringer valleys near the forward bipod (3). Several small, shallow-appearing, divots were noted in the LH2 tank TPS just aft of the bipod (4). Typical SRB separation motor burn scars were seen on the ET TPS near the forward SRB attach points (5).

2.4.2 Analysis of Handheld Photography of the ET (Task #3)

One roll of STS-77 handheld photography was taken using the Nikon F4 with the 300 mm lens plus 2X extender. An early OMS-2 pitch was performed to bring the external tank into view. Four usable frames were acquired for analysis.

2. Summary of Significant Events



Figure 2.4.2 (A) Handheld View of the External Tank

The first picture was taken approximately 16.5 minutes after liftoff (10:46:32 UTC). The -Y axis, -Z axis, and the aft dome were imaged. The external tank appeared to be in good condition on the handheld views. Several pieces of debris (probably umbilical ice) were also imaged.

2. Summary of Significant Events

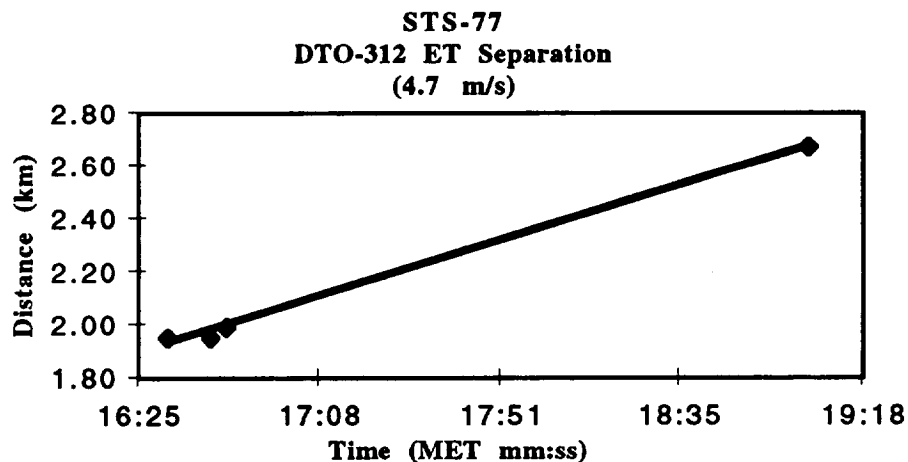


Figure 2.4.2 (B) ET Separation Velocity

The distance of the external tank was calculated over a four frame sequence using the hand held photography. The external tank was calculated to be a distance of 2.0 km away from the Orbiter at 16:32 MET. The tank was calculated 153 seconds later (19:05 MET) to be at a distance of 2.7 km. The tank separation velocity was determined to be 4.7 m/s. The separation velocity was similar to previous mission measurements. The tank tumble and roll velocity were not determined due to insufficient data.

2.5 LANDING EVENTS

2.5.1 Landing Sink Rate Analysis (Task #3)

The main and nose gear sink rates of the Orbiter were determined using landing film over a one-second time period prior to main gear touchdown.

The measured main gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb. vehicle and 6.0 ft/sec for a 240,000 lb. vehicle (the landing weight of the STS-77 Orbiter was reported to be 221,910 lb.). The sink rate measurements for STS-77 are given in Table 2.5.1. In Figures 2.5.1(A), and 2.5.1(B), the trend of the measured data points for film image data is illustrated.

2. Summary of Significant Events

Prior to Touchdown (1/4 Second)	Sink Rate: Film
Main Gear	3.95 ft/sec
Nose Gear	4.92 ft/sec

Table 2.5.1 Sink Rate Measurements

STS-77 Main Gear Sink Rate From Film
(Camera EL9)

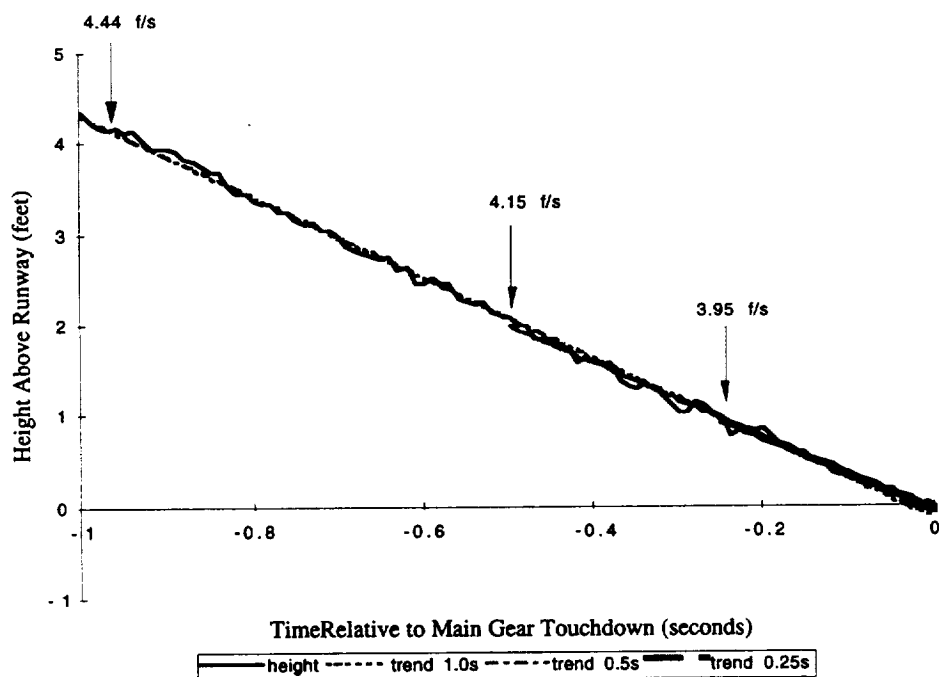


Figure 2.5.1(A) Main Gear Height versus Time Prior to Touchdown (Film)

2. Summary of Significant Events

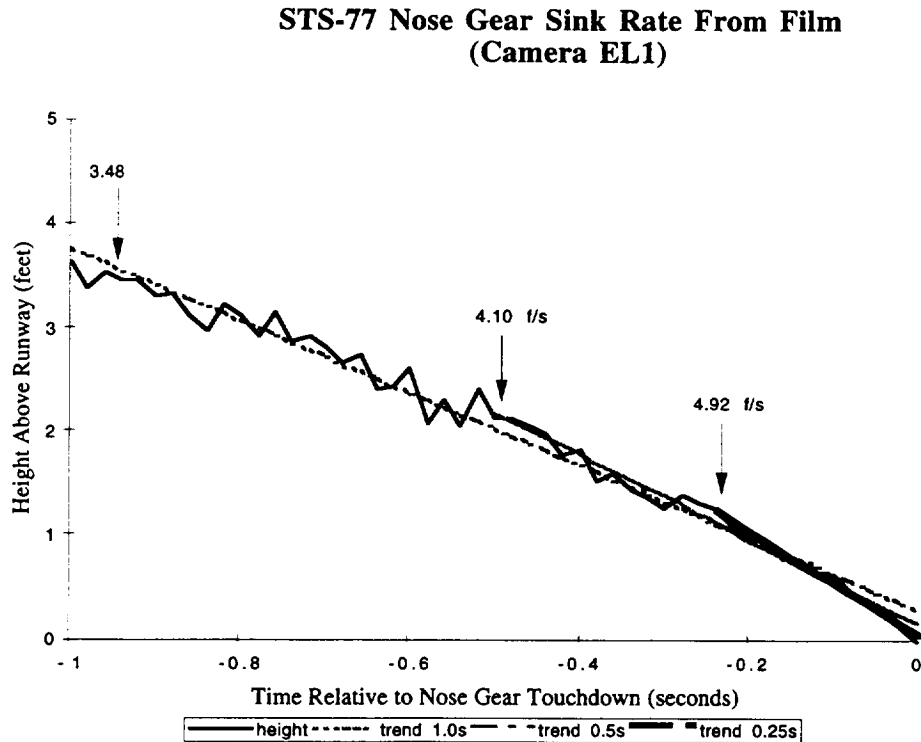


Figure 2.5.1(B) Nose Gear Height versus Time Prior to Touchdown (Film)

2.6 OTHER

2.6.1 Normal Events

Other normal events observed include: Frost on and around the ET vent louvers, frost on the ET LO2 barrel and LH2 tank acreage TPS (+Y side), ice and vapor from the ET/Orbiter umbilical areas from SSME ignition through liftoff, inboard and outboard elevon motion at SSME ignition, body flap motion during SSME ignition and at liftoff, SRB flame duct and MLP debris at liftoff, ET twang, multiple pieces of light-colored debris falling from the LH2 and LO2 TSM T-0 umbilicals at disconnect, ET aft dome outgassing and vapor off the SRB stiffener rings during liftoff, vapor and ice from the GUCP area during ET GH2 vent arm retraction, acoustic waves at liftoff, roll maneuver, linear optical effects, ET aft dome charring, recirculation, SRB plume brightening prior to SRB separation, SRB separation, and SRB slag material after SRB separation.

Normal events seen that are related to the pad are: hydrogen ignitor operation, fixed service structure (FSS) deluge water activation, GH2 vent arm retraction, sound suppression water initiation, mobile launch platform (MLP) water dump activation, LH2 and LO2 TSM T-0 umbilical disconnect, and TSM door closure at liftoff.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY



EP42 (96-20)

June 17, 1996

TO: Distribution

FROM: EP42/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-77

The launch of space shuttle mission STS-77, the eleventh flight of the Orbiter Endeavour occurred on May 19, 1996, at approximately 5:30 A.M. Central Daylight Time from Launch Complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Launch time was reported as 140:10:30:00.009 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team. Photographic and video coverage was evaluated to determine proper operation of the MSFC related flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), LC-39B perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Film was received from forty-five requested cameras as well as video from twenty-four requested cameras. The launch occurred during sunrise at the KSC. A cloud bank in the east lowered the amount of available light significantly making for dark exposures on many of the cameras. All ground-based cameras operated properly.

Five frames of the external tank after separation were obtained by the astronauts with a Nikon 35mm camera. The -Y and -Z axis and the aft dome of the tank were imaged. The orbiter umbilical well cameras (two 16mm motion picture cameras and one 35mm sequence camera) operated properly and obtained good imagery of the ET.

The following observations were made. The typical events of ice/frost falling from the 17" disconnect area, debris induced streaks in the SSME plume, linear optical distortions, flow recirculation, and glowing debris particles being ejected from the SRB plume were noted.

The SSME #2 mach diamond forms before the SSME #3 mach diamond. All other start events appeared to occur normally. The late mach diamond formation of SSME #3 is believed to be a

function of the ambient base pressure and has been observed on previous missions (STS-73, STS-71, STS-60, STS-59).

A long rope-like piece of debris of unknown origin was noted falling aft of the vehicle at T+67.6 seconds. This type of debris has been noted on previous missions.

Two TPS divots were noted at the ET forward bipod strut. One divot was located at the +Y jackpad closeout. The other divot was centered between the bipod struts. It appears that both divots are down to the substrate exposing the primer.

A TPS divot was located at the ET pressurization line ice/frost ramp near station XT1464. This divot appeared to be down to the substrate exposing the primer. Another divot on a pressurization line ice/frost ramp was observed near station XT760.

The following event times were acquired.

<u>EVENT</u>	<u>TIME (UTC)</u>	<u>DATA SOURCE</u>
M-1 PIC Firing	10:30:00.019	Camera E-9
M-2 PIC Firing	10:30:00.019	Camera E-8
M-5 PIC Firing	10:30:00.018	Camera E-12
M-6 PIC Firing	10:30:00.018	Camera E-13
SRB separation	10:32:04.26	Camera E-207

This report and additional information are available on the World Wide Web at URL:

<http://photo4.msfc.nasa.gov/STS/sts77/sts77.html>.

For further information concerning this report contact Tom Rieckhoff at 544-7677 or Jeff Hixson, Rockwell at 971-3082.


Thomas J. Rieckhoff

Enclosure

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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